BIOCYBERNETICS: AN INTERACTIVE MAN-MACHINE INTERFACE

R. F. Thompson, et al

California University

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T. J. Teyler (714) 833-5540
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Project Summary

The research reported here and supported by the Advanced Research Projects Agency of the Department of Defense involves the detection of human bioelectrical phenomena that have been made analogs of ongoing cognitive processes and the utilization of these phenomena to control and/or communicate with external devices. The technique is applicable to situations requiring rapid human intervention in the control of complex systems operation. The major advantage of the procedure is the virtually automatic control of systems by the trained subject.

We are training human subjects to respond to alpha-numeric symbols such that a discriminable response is obtained for each symbol. The symbols are an abbreviated list of the English alphabet. The bioelectric response is the electromyogram (EMG) recorded from the surface of the skin overlying muscle. The actual training was accomplished initially on an off-line logic device and later by an interactive computer programmed to present stimuli and deliver reinforcements of various kinds to the subjects given the appropriate response code. This year's final report covers the preliminary training procedures and the instrumentation and software developed in support of the project. To provide a perspective for this year's accomplishments, a brief resume of subsequent project goals are presented below.

As the project proceeds the subjects will be required to correctly codify increasingly complex stimulus patterns, such as simple words or phrases. We will also train subjects to interpret machine generated codes presented through EMG recording electrodes, thus incorporating the provision for machine-to-man as well as man-to-machine communications.

Concurrent with these efforts we also plan to record EMG potentials from the vicinity of the oral cavity (laynyx, tongue) to investigate the feasibility of performing pattern recognition analysis on these responses which have been implicated in subliminal vocalization. We also will record and analyze brain potentials from the surface of the scalp in an attempt to obtain an even more "central" measure of cognitive functioning than the EMG measures described above.

The immediate applications of this research are in 1) the development of computer systems to decode and analyze human communication - in this respect we view this program as an alternative or adjunct to current efforts involving the development of a machine capable of decoding human voice; 2) monitoring the reactions and decision making processes occurring in stressful, complex, or persuasive situations; 3) situations requiring rapid and continuous feedback of systems operations to the human controller; 4) situations wherein interactive communication between man and machine are desirable but not currently practical because of time restraints or environmental restraints.

System and Procedural Overview

The long range objective of this project is the development of an efficient and accurate man-machine interactive method, involving use of biofeedback control. As such, it is our goal to utilize clearly structured bioelectrical aspects of human response generation and decision making. The major advantage of this goal is virtually automatic interactive systems control by trained subjects.

We are currently training subjects to respond to alpha-numeric symbols such that a discriminable response will be obtained to each symbol. The symbols are a truncated set of the English alphabet. The response is the electromyogram (EMG) recorded from the surface of the skin overlying muscle. The EMG is most directly an index of motor nerve activity rather than of muscle activity level since the magnitude of the electrical response is a direct function of the amount of neural activity imposed upon the individual motor units of skeletal musele. The EMG is always present upon sufficient neural activity to elicit muscle movement and is also detectable given neural activity insufficient to generate movement. Interestingly, when a subject is instructed to "think about" flexing a specific muscle, a recording of the EMG accompanying this cognitive process is possible. In short, the EMG has the unusual property of being activated by the mere thought of activating the response system, e.g., the muscle (Leuba & Dunlap, 1951). This property of the EMG has been known for years (Hefferline & Perera, 1958) and has been utilized in several applied bioengineering

situations, most notably the eontrol of prosthetic devices. In this ease the subjeet, with sufficient training, beeomes quite adept at eontrolling his prosthetie deviee and reaehes the point where he need not aetively eonceptualize a musele movement to produee the EMG signals necessary to eontrol the limb and reach his goal, but merely "thinks" of the desired movement to be performed. The thought of the movement is suffieient to produee the neeessary EMG's. Later in his training he need not even think of the movements neeessary to reaeh the goal, but merely thinks of the goal with the same laek of direet, eonseious commands as does an intaet human. It follows, of course, that the museles used to control the limb cannot be oecupied with other tasks that would produee error commands.

The project reported herein deals with the eapability of training a human subjeet to eontrol and/or interaet with complex eleetronie or mechanical systems. Basically the project involves the deteetion of bioelectrical phenomena that are analogs of ongoing eognitive processes and the utilization of these phenomena to eontrol external events. The projeet also allows the system being controlled to eommunieate with the human operator in either a feedbaek or an interaetive manner. In bypassing the subjeet's manual or verbal response apparatus an appreeiable time saving may be achieved. By eliminating the normal feedbaek/ interactive modes of communication eurrently employed by maehines (generally visual signals produeed mechanically or electronically) a further potential time saving ean be realized.

We have achieved the initially described first year objectives during the past eight months of the project. In essence these were twofold: 1) develop the interactive systems hardware and software, and 2) train subjects to generate and respond correctly to alpha-numeric symbols using EMG responses.

The semi-annual report (January 1 to June 30) described initial development of a partially hard-wired system (the final system required additional computer equipment which was only delivered in September, 1972) and initial subject training.

A central instrument in the conduct of this project is the augmented computer configuration. Since we have completed the transition from off-line logic control to on-line control and analysis, we are now in a position from the computational point of view to be able to acquire up to 24 simultaneous EMG and EEG records as necessary to support the various tasks defined for subsequent years. This acquisition capability in conjunction with the data storage and computational capability in the form of the disc facility and the floating point processor provide a highly flexible tool for use in the accomplishment of the defined task sequences.

The software which was developed before delivery of the addon equipment was oriented toward the control of the training program. We are currently expanding these software sets to utilize the full capabilities of the system.

Subjects have been trained to generate 16 different muscle patterns on cue. The process of training subjects to generate these precisely

defined motor responses to visual stimuli proceeds from a simple match-to sample task to the codification of a truncated alphabet by use of these defined sets of responses. The responses currently being directly trained are the electromyographic (EMG) records from the skin surface overlying four muscles.

Left and right flexor pollicis brevis (thumbs)

Left and right obductor digiti minimi (little fingers)

Subjects are required to generate these EMG responses without appreciable movements of the muscles or fingers. This aspect of the task--generating the EMGs--has proved easy for subjects and surprisingly "enjoyable" for them. They report that it is "fun" to do it with the attendant computer biofeedback. We have emphasized use of immediate visual feedback in training to date. It is in fact remarkable how rapidly well trained subjects can generate the alpha-numerics and how quickly untrained subjects can learn the task. We were pleasantly surprised that training naive subjects proceeds so fast. We have a strong impression that the manual capabilities of man, utilized in terms of EMG activity rather than substantial movements, far exceed expectations based on current manual task requirements.

This final report for the first year of the project encompasses three areas. These are reports of:

Methods and techniques involved in the overall training procedures.

Permanent subject performance under several paradigms.

Short term subject performance under a multimode feedback situation.

Each of the topics will be considered in a separate section.

Technique and Methods

The initial task was addressed to the problem of selecting EMG recording sites. The criteria for selecting muscles to be used were as follows: The muscle must be superficial and not lie under an overly thick layer of adipose tissue which would act as an electrical shunt. The muscle had to be reasonably large such that a detectable EMG would be generated given minimal neuromuscular activation. Since our task will eventually require very rapid patterns of responses the muscle had to be capable of responding at high rates of brief contractions. We have limited ourselves to surface recording of the EMG with disc electrodes. This necessitated a recording site which was not affected by the activation of other muscles lying adjacent to our target muscle. Thus, we were seeking a muscle which was relatively anatomically isolated. A prime consideration dealt with the possible confounding effects of using muscles which might be expected to be utilized in normal postural control. For this reason we eliminated most of the large muscles of the limbs (they also are incapable of responding at high frequencies). After trial we eliminated the muscles of the face and head because they were 1) too small and 2) were involved in largely involuntary movements associated with respiration, swallowing, eye blinks, etc. Since we want to utilize a rather subliminal muscular contraction a muscle with as high an innervation ratio as possible would be desirable. Finally, for practical reasons, the muscle had to be readily accessible without embarrassment or discomfort due to electrode placement.

Muscles that were considered and rejected for one or more of the above reasons included: frontal and occipital epicranius, orbicularis oculi, superior auricular, depressor labii inferioris, maseter, trapesius, biceps brachii, brachioradialis and other superficial muscles of the forearm. The muscles deemed most suitable for this project were the flexor pollicis brevis (flexion and adduction of thumb) and the abductor digiti minimi (abducts little finger) both intrinsic muscles of the palmar surface of the hand. To simplify the subject's task we have utilized four muscles giving 16 response combinations. From these 16 combinations (discrete response plus no response) one can construct a communicable alphabet (see Appendix A).

Once chosen the muscles were mapped on the surface of the overlying skin to determine the location yielding the best signal to noise level. Using differential amplification the most satisfactory results were obtained by placing the active electrode over the belly of the muscle and the indifferent over the distal tendon. All recording configurations employ earlobe grounding. Amplifier gain was from 30-150 V/cm. (Grass polygraph--EEG channel) with a bandpass of 1 to 75 Hz. Figure 1 shows a recording from the flexor pollicis brevis (brevis) and abductor digiti minimi (minimi) for both hands. The subject here is performing low amplitude twitches of the muscles at will.

Testing and training took place in a sound-attenuating, ventilated chamber which was dimly lit (see Figure 2). The subjects sat in a comfortable, stuffed chair and were not required to utilize any of

Figure 1 Polygraph recording of EMG's obtained from relatively untrained subject instructed to perform low amplitude twitches of four muscles at will. Minimi refers to the abductor digiti minimi (little finger); brevis refers to flexor pollicus brevis (thumb).

Gain = 75 μV/cm; speed = 2.5 mm/sec.

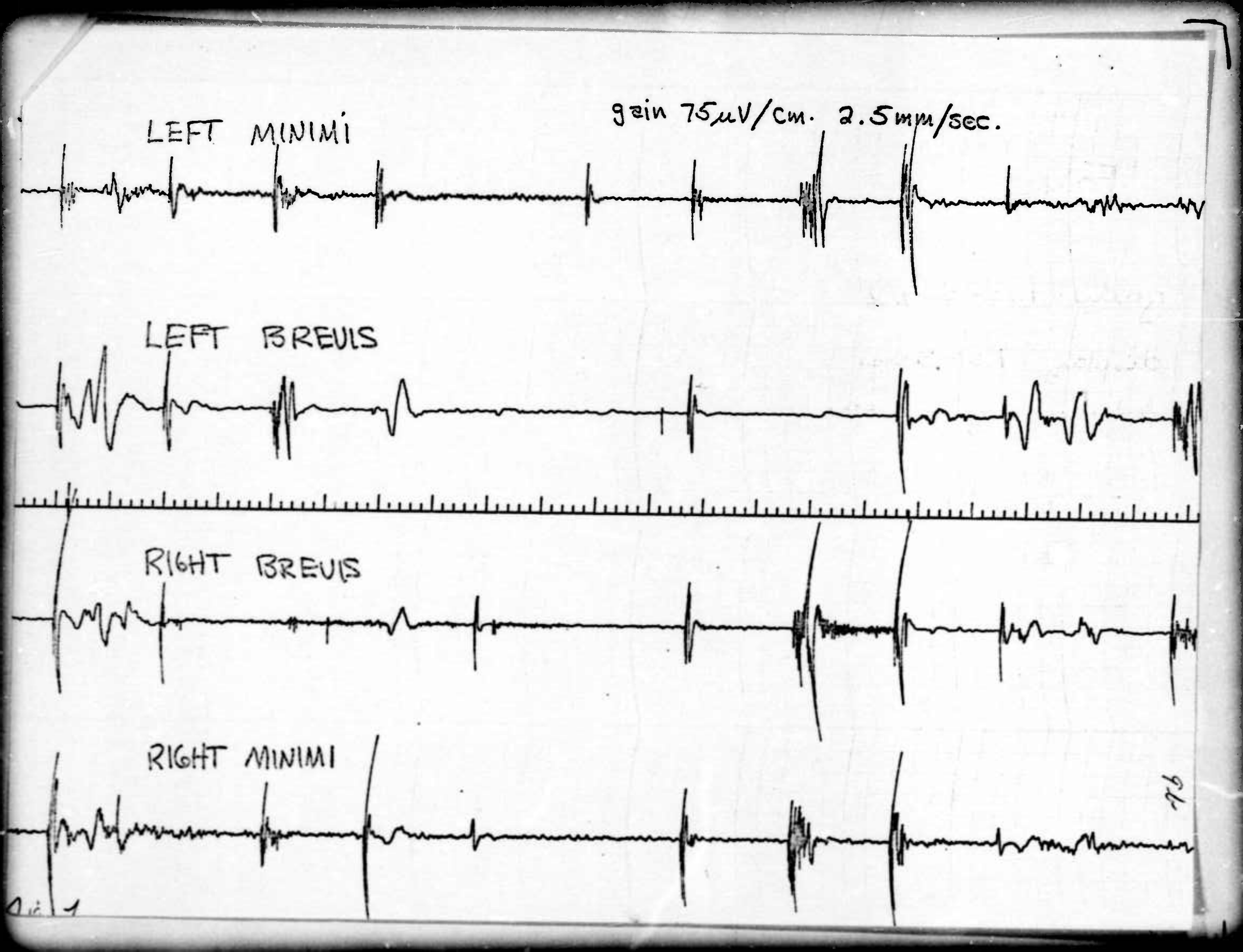
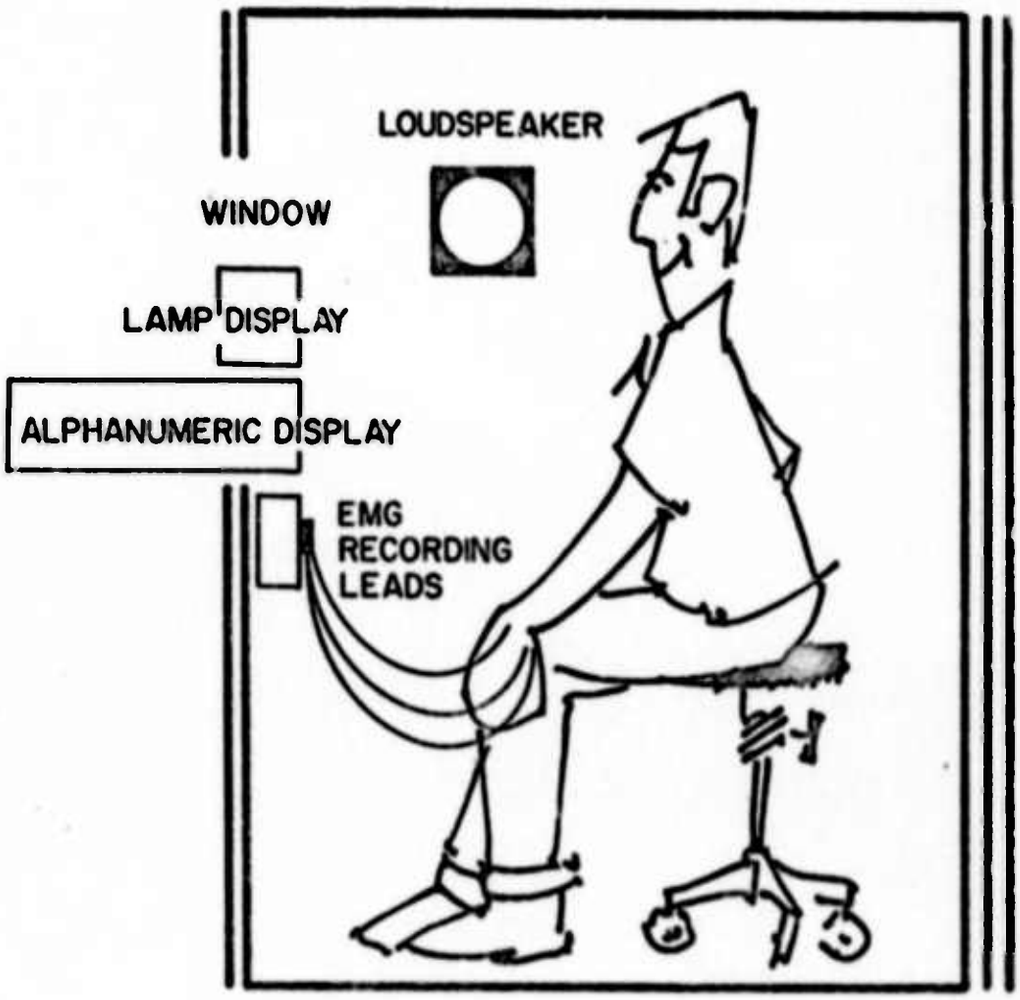

LEFT MINIMI
gain 75μV/cm. 2.5mm/sec.
LEFT BREVIS
RIGHT BREVIS
RIGHT MINIMI

Figure 2 Physical arrangement of the training facilities.

PHYSICAL ARRANGEMENT



SOUND ATTENUATING ROOM

their musculature to remain in a comfortable position. Subjects faced a window in the room through which they saw the lamp display and alphanumeric display devices (to be described later). A black cloth around these units reduced distracting visual stimuli to a minimum. The EMG was recorded using gold disc electrodes and electrode paste and held on with tape.

Patterned Light Training

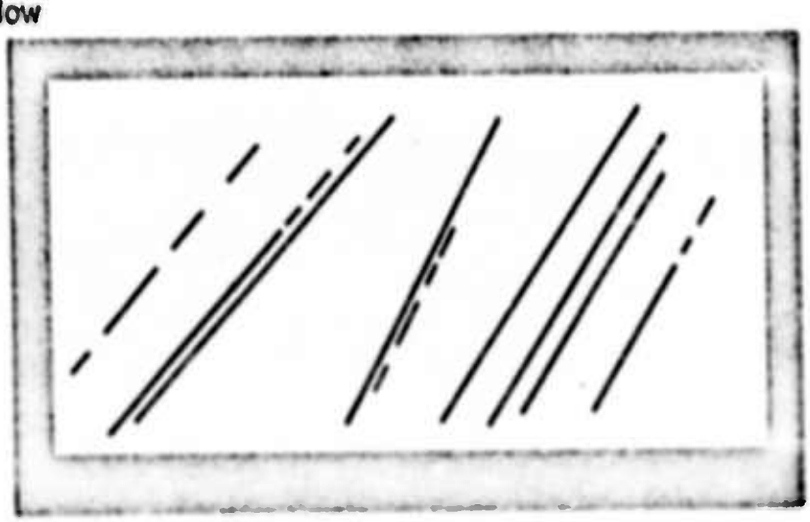
Each of the truncated list of English alphabet characters has been assigned a particular code (see Appendix A). These codes can be considered as four lamps which can be lit or dark in various combinations. Thus, to train subjects we employed a lamp display panel (see Figure 3). The display consists of two rows of incandescent lamps. Lamps in the top row have orange lenses, the lamps on the bottom are green and the single lamps on the extreme right and left are red.

Rather than initially present the alphanumeric display and the associated code as displayed on the lamp display we first trained the subjects to respond correctly to the lamps alone. It was felt that this was a somewhat simpler task and that the alphanumeric display could be added later. The task consisted of the presentation of a pattern of lit lamps on the upper row. The upper row of lamps for convenience are referred to as the S code (Stimulus Code) lamps. The subject was to turn on the lower row of lamps such the pattern of lit lamps in the two rows coincided. The lower row of lamps will be referred to as the R Code (Response Code) lamps. Thus, the task is a match-to-sample paradigm.

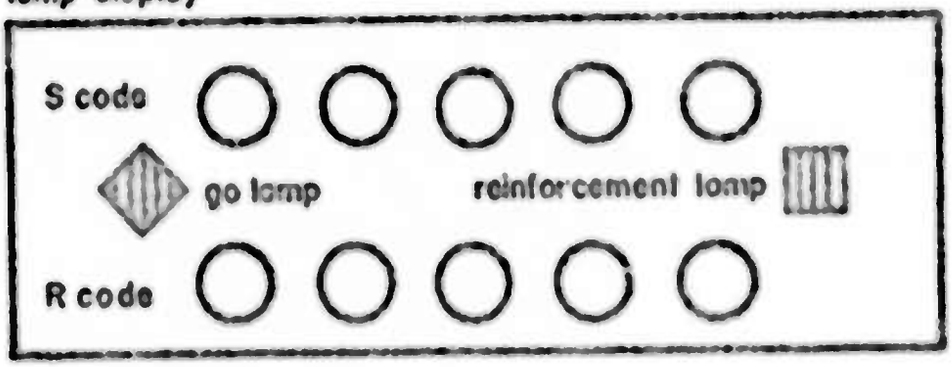
Figure 3 Representation of the interactive display devices. The subject is seated 1 meter in front of the window.

INTERACTIVE DISPLAY DEVICES

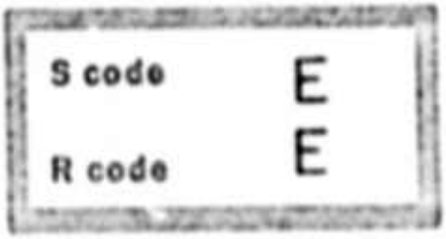
window



lamp display



alphanumeric display

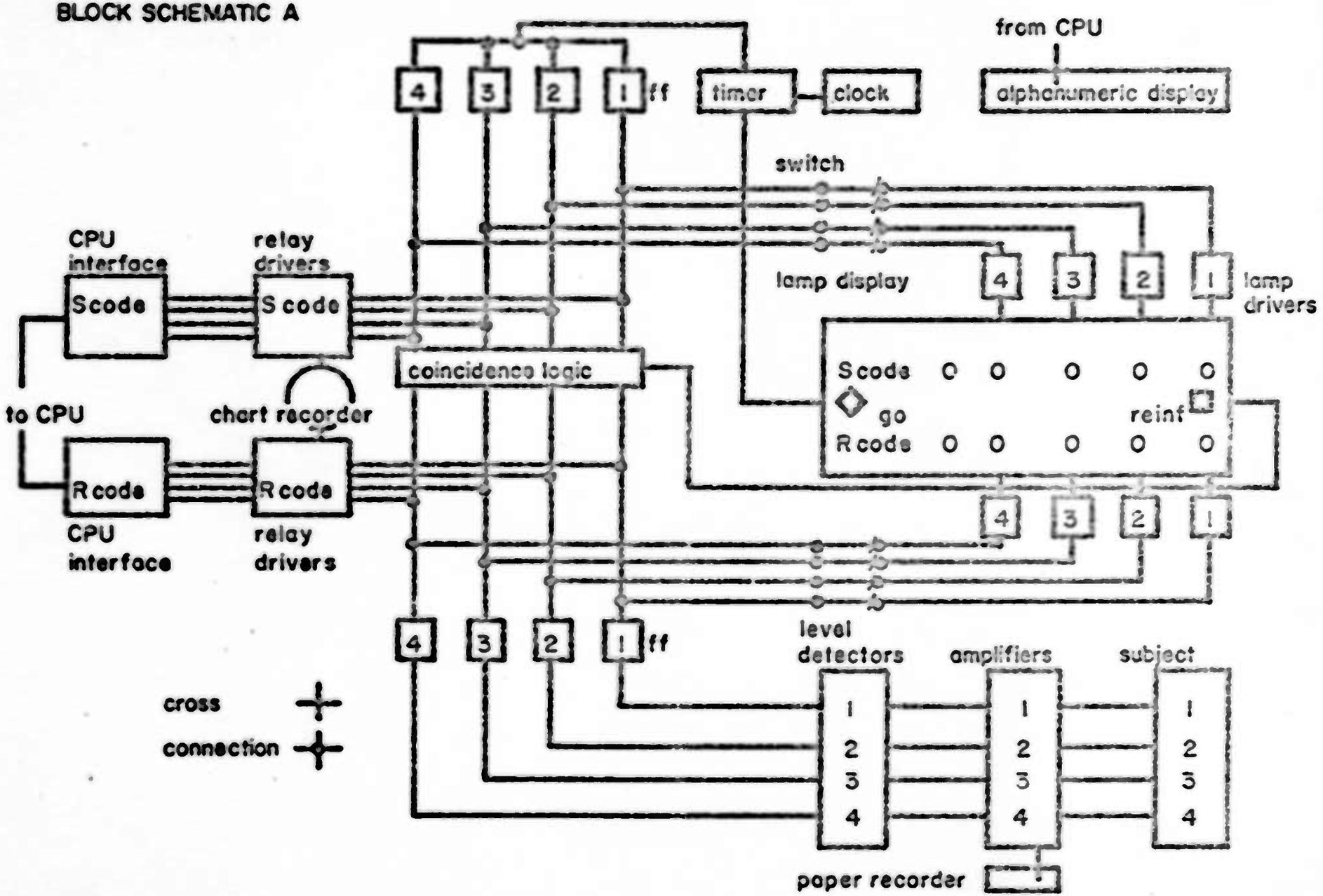


Every 6-10 seconds the S Code was displayed for a variable period of time (from 3 sec down to 1/4 sec as training progresses). At the same time the left hand red lamp is lit signalling the start of a trial (termed the GO lamp). The subject then issues a response. If successful in matching to the sample the right hand red light is lit (reinforcement lamp). At the end of the trial the lamp display panel is turned off.

The initial training was accomplished with logic devices as shown in Figure 4. The four channels of EMG information were amplified and simultaneously written onto a pen-writing polygraph. The amplified and filtered EMG was fed into a series of level detectors which produced standard logic level pulses when the voltage of the EMG exceeded a preset level. The output of the level detectors set R Code flip-flops which in turn activated lamp drivers providing a visual lamp display. The output of the R Code flip-flops in addition activated two interfaces; one to a chart recorder for a printed record of response, the other to the computer external sense lines.

The S Code presented on any trial was randomly determined by a highspeed digital clock that transferred its count to the S Code flip-flops upon command from a timer. The flip-flops in turn activated the lamp drivers and S Code lamps of the display panel. The S Code, too, was routed to a chart recorder and the computer. The reinforcement lamp was lit when the output of the coincidence logic indicated that the R Code equalled the S Code. Twenty-five trials constituted a block and a session contained ten blocks.

Figure 4 Block Schematic A. Logic devices utilized in initial training.

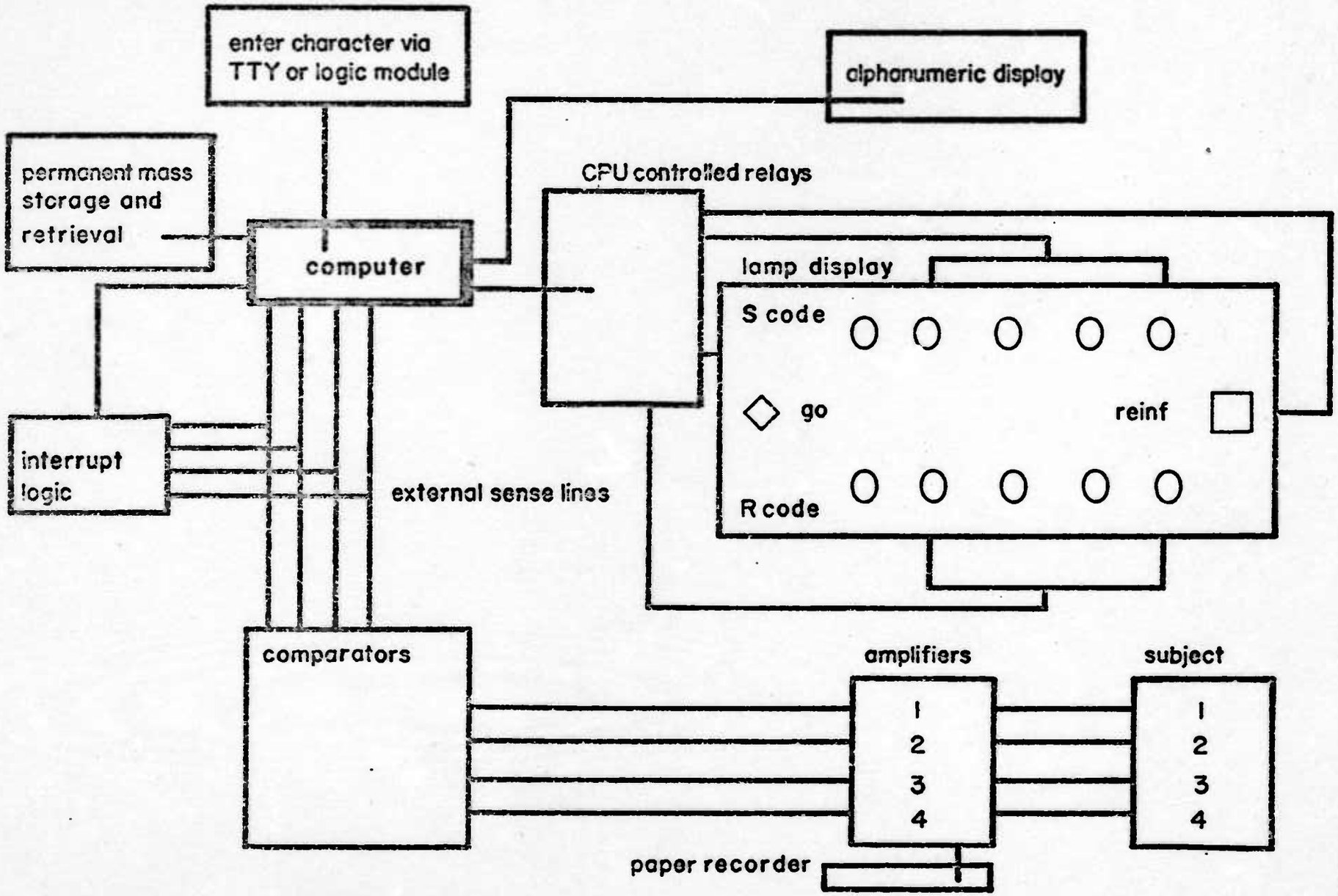

BLOCK SCHEMATIC A
from CPU
4
3
2
1
ff
timer
clock
alphanumeric display
switch
CPU interface
relay drivers
Scode
Scode
lamp display
4
3
2
1
lamp drivers
coincidence logic
Scode 0 0 0 0 0
go
reinf
Rcode 0 0 0 0 0
to CPU
chart recorder
Rcode
Rcode
CPU interface
relay drivers
4
3
2
1
4
3
2
1
ff
level detectors
amplifiers
subject
cross
connection
1
2
3
4
1
2
3
4
1
2
3
4
paper recorder

The next phase of training and system development involved the association of the S Code lamps with a particular alphanumeric display. Referring back to Block Schematic A (Figure 4) note that the S Code was relayed to the computer. A program was developed (Appendix B) to decode the S Code and display the appropriate alphabetic character on the remote display unit for the subject to view. The results of this stage are discussed in the section dealing with permanent subject training and performance.

The use of control logic left much to be desired in terms of reliability, flexibility and convenience. Consequently, we redesigned the control and analysis sytems to shift system control and monitoring to the computer. Block Schematic B (Figure 5) depicts the current system configuration. A new computer program (Appendix C) was developed to support the new configuration. The EMG "R Code" is captured in the same manner as previously but is now routed to a series of comparators to perform an analog to digital conversion. The computer external sense lines then permit decoding of the R Code under software control. As a function of the detected R Code and at the experimenter's option the computer can 1) activate the R Code lamps for patterned visual feedback; 2) activate audio oscillators which are spatially arranged for auditory feedback; or 3) display the R Code alphabetic character on the alphanumeric display unit as a form of cognitive feedback.

Figure 5 Block Schematic B. Systems configuration to support the experimental control and data analysis of the project.

BLOCK SCHEMATIC B



The S Code is generated either by a random logic device or by manual intervention through the computer's tel_type device. The computer presents the S Code and monitors the sense lines for the R Code. While monitoring and matching the R Code to the S Code, the computer constantly updates the feedback options with the current R Code responses. When a match is detected between the S Code and R Code the computer signals a reinforcement.

Under the control logic system we could only determine the total number of correct responses during trials. This program provides a letter by letter analysis for each trial consisting of an indication of the S Code, the subject's response, and the latency for each muscle group in milliseconds.

This provides the substrates for a much finer grained analysis of these behavioral properties. Appendix D contains the computer programs used for the analysis of data acquired this procedure.

We are currently developing a program which provides the capability of multi-character S Code and R Code control and analysis. This program will also provide for incorporation of the analog-to-digital capabilities for EMG and EEG patterns analysis scheduled for year #2.

Permanent Subject Training and Performance

Using the procedures described previously we have two permanent subjects in different stages of training. The first subject was initially trained with the logic control system and her training has continued after the transition to computer control. The second subject began training after the implimentation of the computer control system. Consequently, the training for the two subjects has differed slightly.

Preliminary Training Both Subjects

We noticed that although the two muscles on each hand are well separated that the contraction of one was accompanied by the activation of the other to a noticeable degree. Our first step was to eliminate this interaction. To this end we placed a 4-trace oscilloscope in front of the subjects. The subjects saw each EMG channel and received immediate visual feedback that served two functions. One, it effectively eliminated the muscle interactions by allowing the subjects to observe and suppress the "wrong" response. Secondly, it gave the subjects a "feel" for what kinds of bioelectric signals she could produce.

During this phase of training, the subjects were instructed to twitch their muscles at will and simply observe the oscilloscopic display. The subjects were asked to attempt to twitch each muscle independently and in various combinations. They were also asked to

make smaller and smaller twitches. The subjects found these tasks relatively easy. In fact at the end of this phase of training the subjects were able to issue quite respectable potentials (about 50-100 μV) without any apparent movement.

PERMANENT SUBJECT ONE

Alphabetic Training

The initial alphabetic training for this subject was with the logic control system. The subject attained 90 to 95% correct match-to-sample responses at 1 sec display time after 1000-1500 trials. Figure 6 presents a polygraph record of the subjects performance at the end of this phase of training. As can be seen the baseline is relatively quiet. Most of these responses occur in the absence of any overt twitch.

Figure 7 presents the results of a session after the subject had mastered the match-to-sample task. In this particular session the subject was exposed to four different display times: 3.0, 2.5, 1.5 and 1 sec. Plotted are the percent correct responses per block for the various display times. As can be seen the longer display times represented a relatively easy task. At one second display times the subjects performance improved from 50% correct (where 6% is the chance level) to 85% correct in three blocks. Interestingly when the subject made an error there was often an increase in intertrial responses. This probably reflects an emotional response on the part of the subject to the cognizance of making an error. At the end of this phase of alphabetic training the subject evidenced a high degree of control over the EMG responses to the S Code lamps.

Figure 6 Polygraph recording of EMG's obtained from a subject well trained on the lamp display match-to-sample task. Gain = 50 μV/cm; speed = 5 mm/sec.

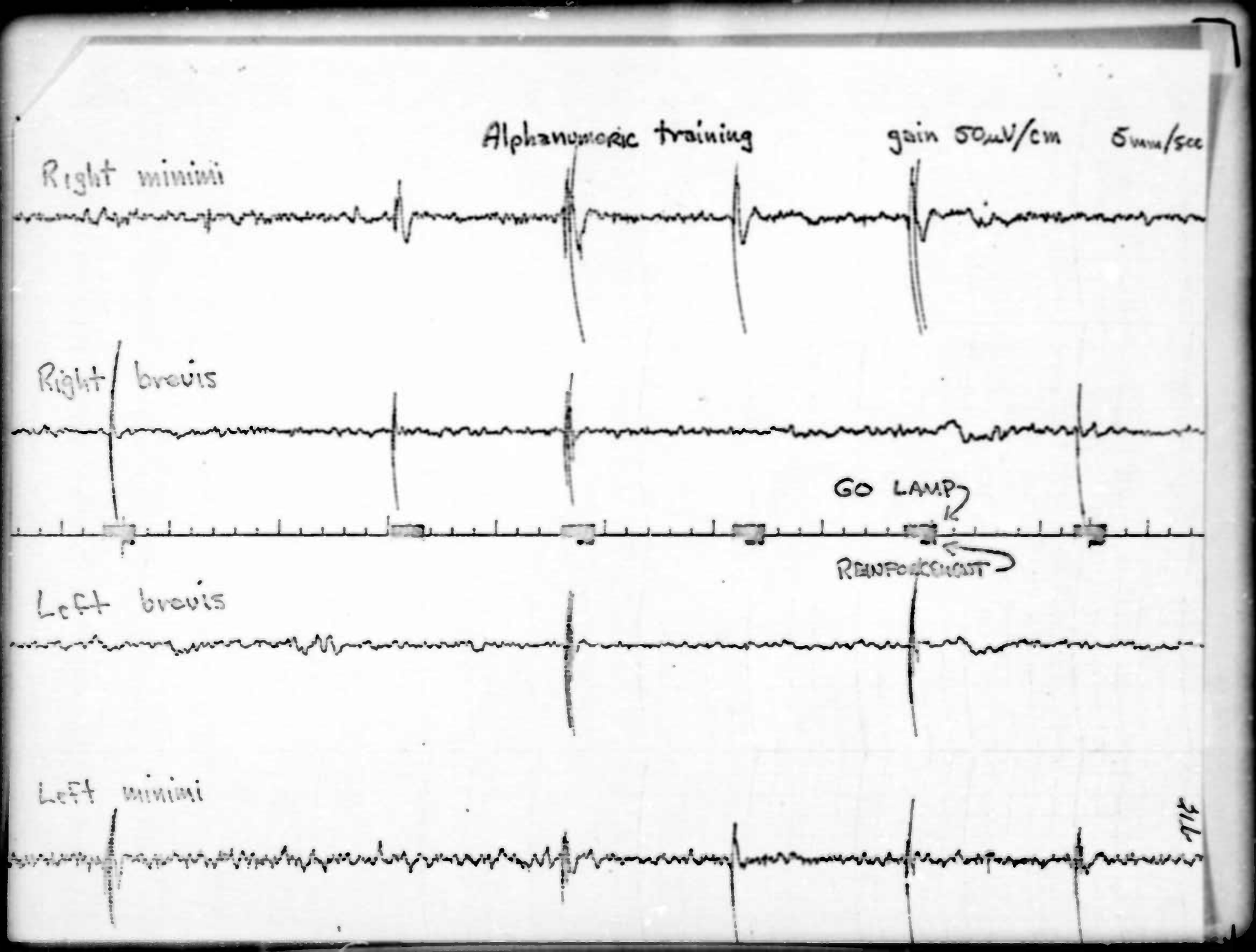
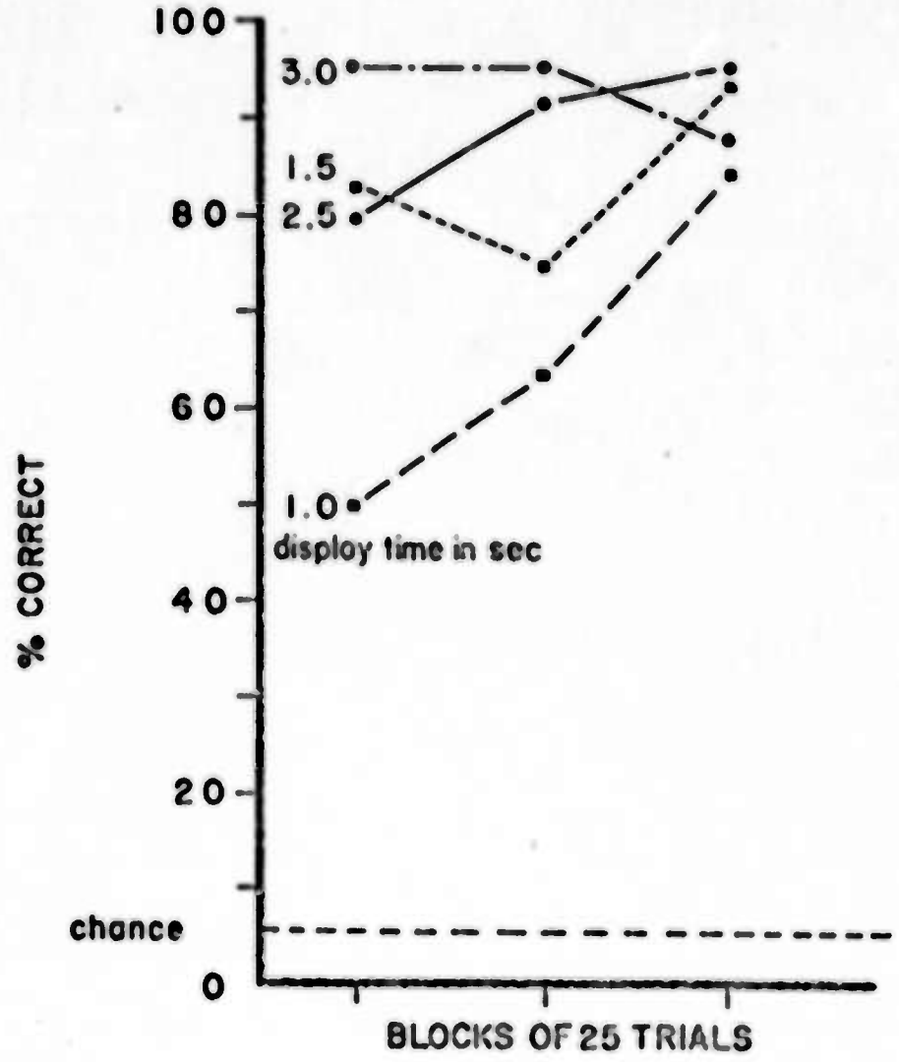

Alphanumeric training
gain 50μV/cm
5 mm/sec
Right minimi
Right brevis
GO LAMP
REINFORCEMENT
Left brevis
Left minimi

Figure 7 Results of a final session of lamp display match-to-sample training. Plotted are the percent correct responses per block of 25 trials as a function of display time.


100
80
60
40
20
0
% CORRECT
3.0
1.5
2.5
1.0
display time in sec
chance
BLOCKS OF 25 TRIALS

The subject learned the association in several sessions. The S Code lamps were then turned off leaving only the alphabetic character displayed. The R Code lamps, the GO lamp and reinforcement lamp were still present. Figure 8 presents the results of a session of alphabetic display training only. In this session the characters were displayed for either 2.0 sec or 1.0 sec. It is apparent that the longer display is again an easier task. These data were also analyzed for a trials effect across blocks within the session (Figure 9). The 25 trials were collapsed into five blocks of five trials. The data are expressed for the 1.0 sec display time, the 2.0 sec display time, and for both display times pooled together. Across trials one can see that performance improved but that it falls off somewhat at the end of the block. This latter effect may reflect a fatigue phenomena which might be alleviated by either a longer inter-trial-interval or fewer trials in a block.

With implementation of the augmented computer facility we were able to accomplish more detailed performance analyses as noted previously. In this context, we have identified letter by letter performance characteristics for this subject. Figure 10 depicts the percent correct of responses for each letter for this subject with a 2 second display time. The number associated with each letter is the arbitrary octal code assigned per Appendix A. Figure 11 reflects performance with a one second display time, while Figure 12 reflects a 280 millisecond display time.

Figure 8 Results of a session of alphabetic display training. plotted are the percent correct responses per block of 25 trials as a function of display time.

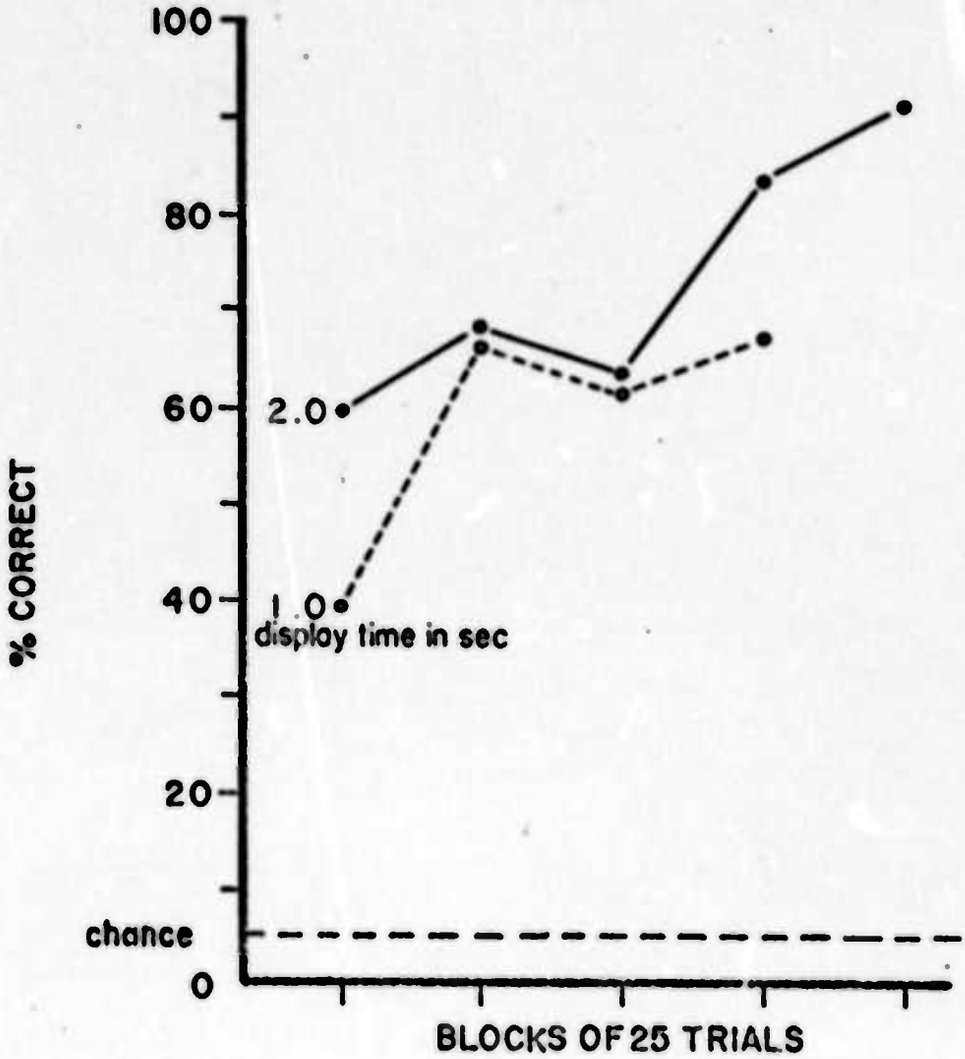

100
80
60
40
20
chance
0
% CORRECT
2.0
1.0
display time in sec
BLOCKS OF 25 TRIALS

Figure 9 Results of the alphabetic display training analyzed for a trials effect across blocks within a session. The 25 trials were collapsed into 5 blocks of 5 trials each. Plotted are the percent correct responses per 5 trial block as a function of display time (1.0 sec display, 2.0 sec display, and both display times pooled together).

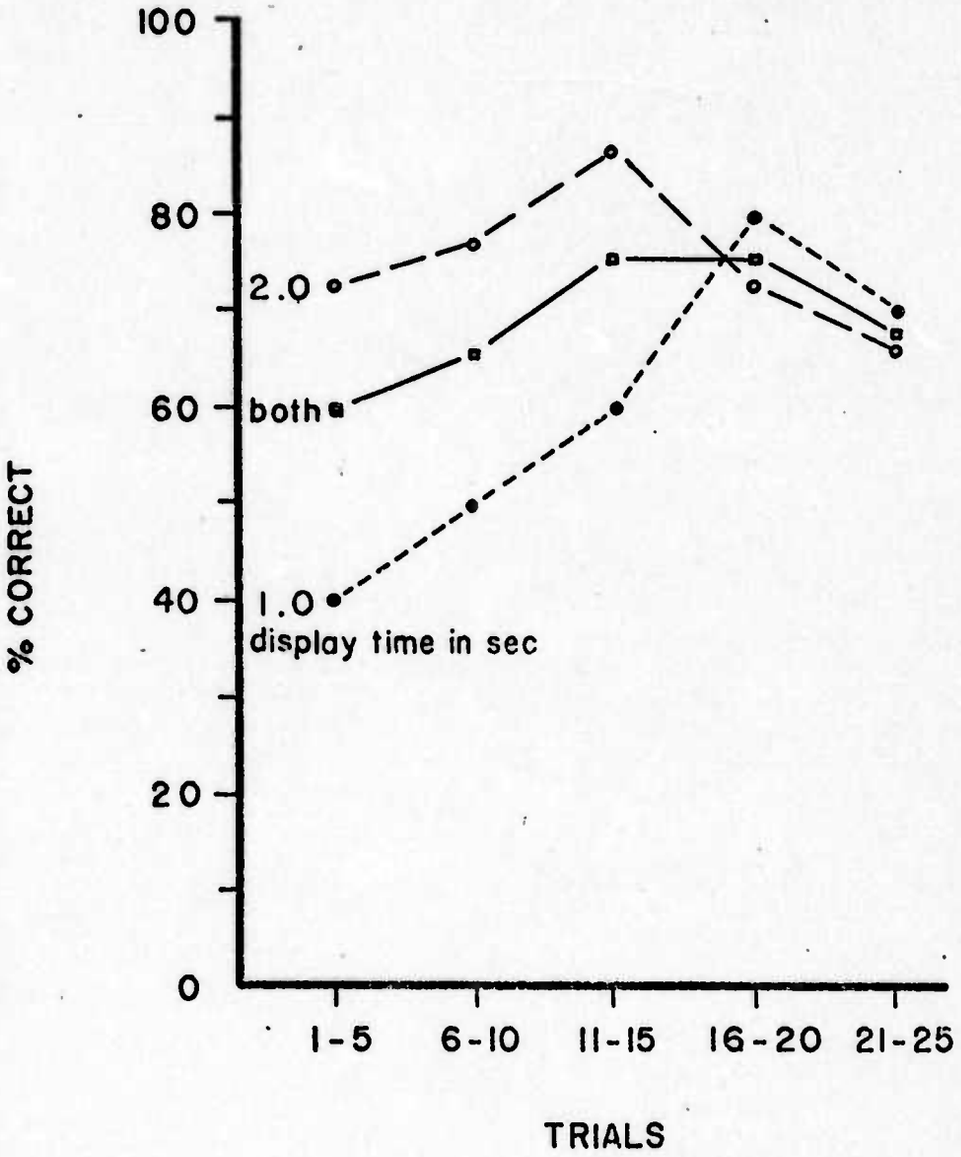

100
80
60
40
20
0
% CORRECT
2.0
both
1.0
display time in sec
1-5
6-10
11-15
16-20
21-25
TRIALS

Figure 10 Results for alphabetic training from five daily sessions of 256 trials each. Plotted are the sixteen alphabetic responses and the overall performance in percent correct responses. Display time here is 2 seconds.

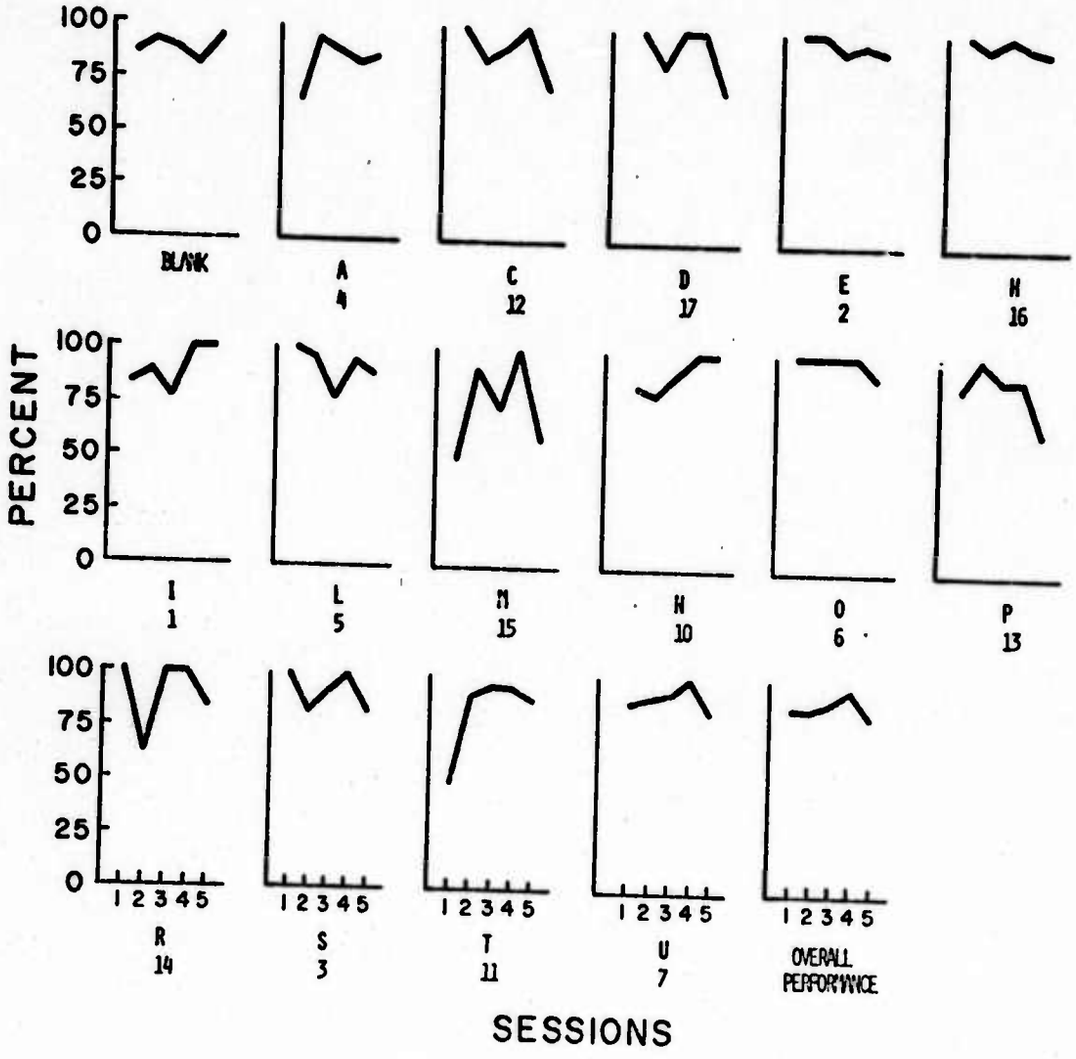

100
75
50
25
0
PERCENT
BLANK
A
4
C
12
D
17
E
2
H
16
I
1
L
5
M
15
N
10
O
6
P
13
R
14
S
3
T
11
U
7
OVERALL PERFORMANCE
1 2 3 4 5
SESSIONS

Figure 11 Results for alphabetic training from four daily sessions of 256 trials each. Plotted are the sixteen alphabetic responses and overall performance in percent correct responses. Display time 1 second.

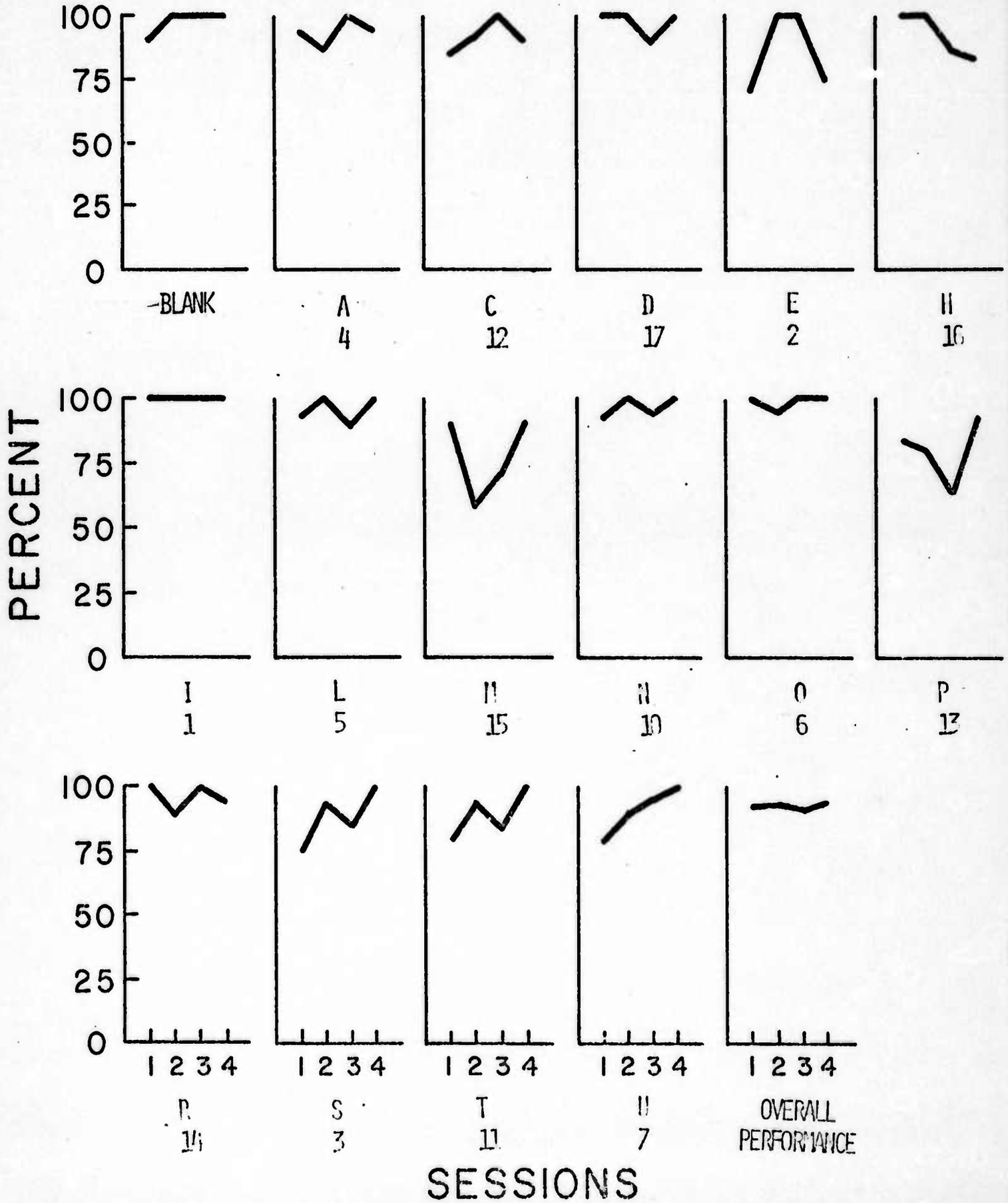
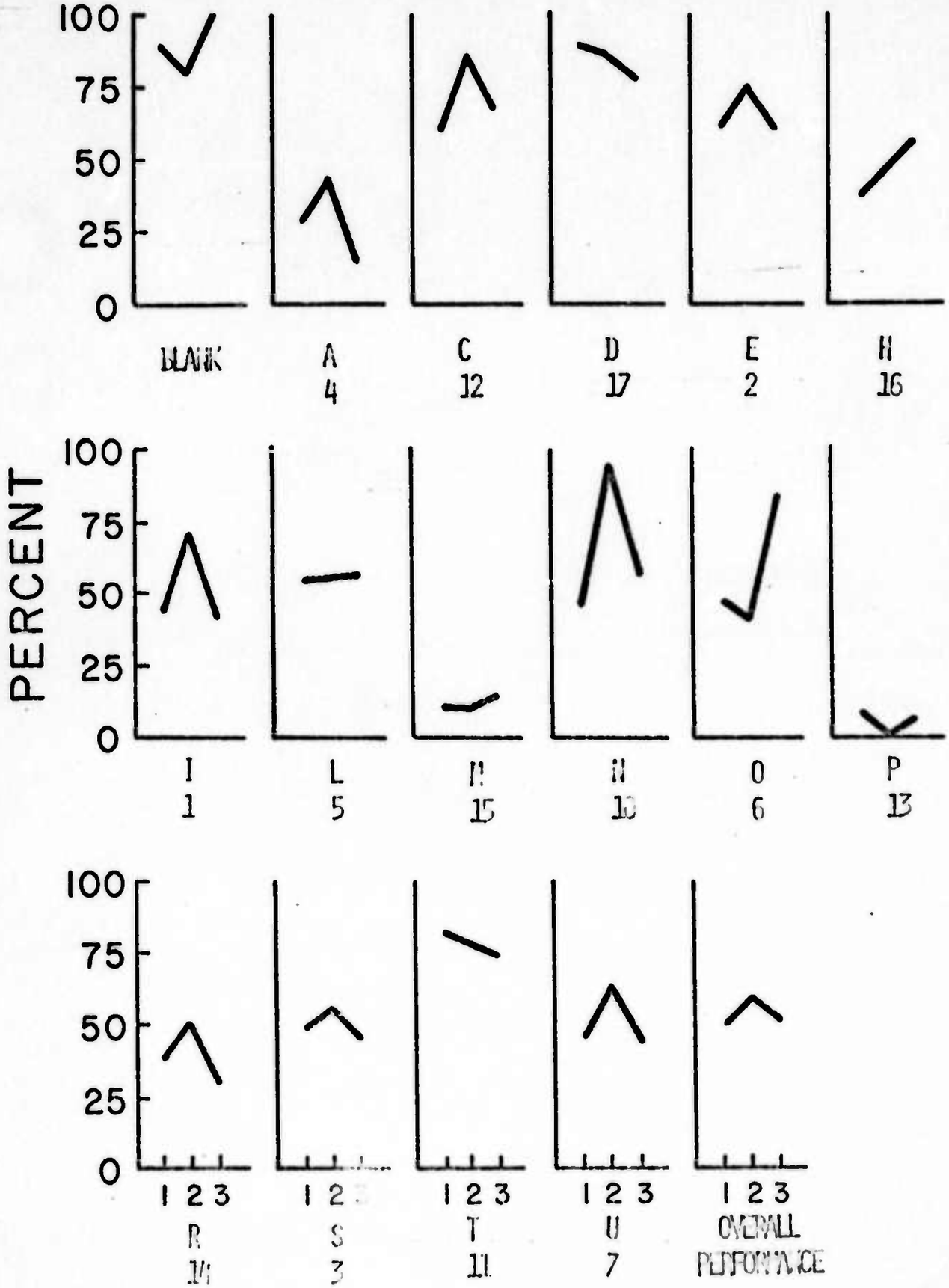

100
75
50
25
0
PERCENT
-BLANK
A
4
C
12
D
17
E
2
H
16
I
1
L
5
M
15
N
10
O
6
P
13
R
14
S
3
T
11
U
7
OVERALL
PERFORMANCE
1 2 3 4
SESSIONS

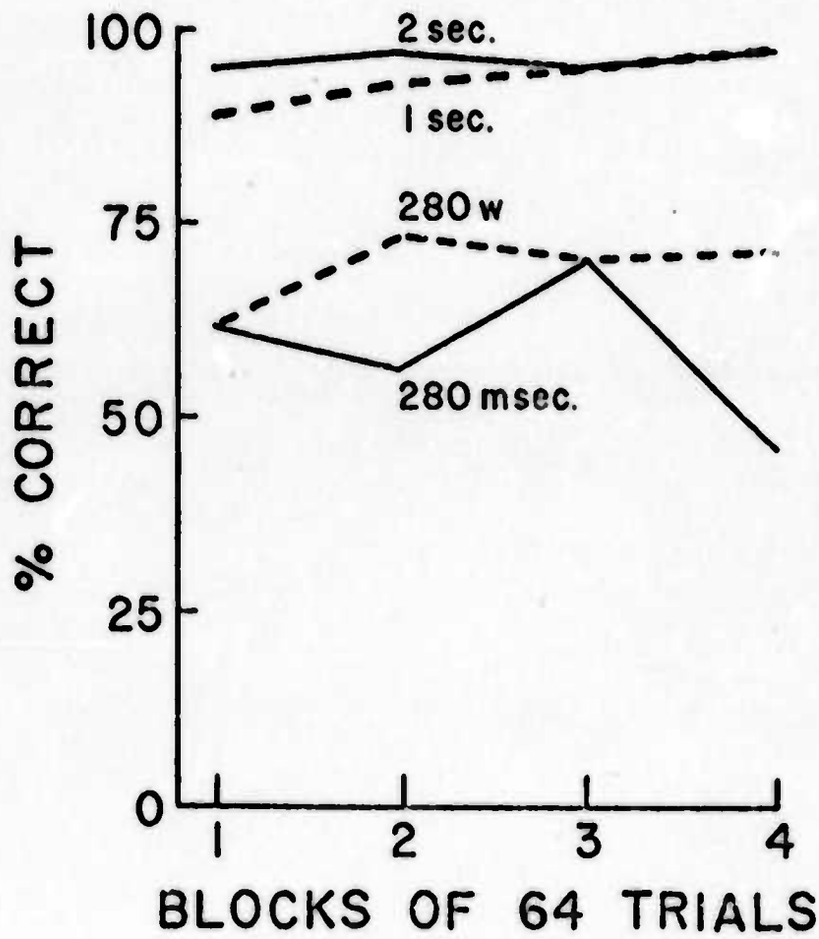
Figure 12 Results for alphabetic training from three daily sessions of 256 trials each. Plotted are the sixteen alphabetic responses and overall performance in percent correct responses. Display time is 280 milliseconds.


100
75
50
25
0
PERCENT
BLANK
A
4
C
12
D
17
E
2
H
16
I
1
L
5
O
6
P
13
R
14
S
3
T
11
U
7
OVERALL
PERFORMANCE
1 2 3
SESSIONS

As can be seen in Figure 11 this subject's overall performance exceeds 90% correct at a 1 second display time. When display times are reduced to 280 milliseconds (Figure 12) overall performance levels drop to about 50%. This is to be expected since this display rate approaches the limit of human performance for a visual motor reaction task with a vigalence component. Only one response pattern falls to chance level (the pattern for the letter "P"), the rest continues to be performed at a level significantly above chance performance.

A crucial point to recall, here, is that during the trials the subject does not know what the next response requirement will be. Consequently, she must wait until a stimulus is presented and then select and initiate the appropriate response. The subject is required to perform at a rate selected by the system as opposed to performing at her own selected rate. The effect of this is suggested in Figure 13 where performance at 280 msec with warning is better than without warning. The performances reflected in Figures 10 through 12 were also analyzed for a trials effect similar to that of Figure 9 (Figure 13). In this case 256 trials were collapsed into four blocks of 64 trials. The data are expressed for display times of 2 seconds, 1 second, 280 millisecond, and 280 millisecond preceded by a 1 second warning light. Performance is essentially asymptotic with the 2 second and 1 second displays (compare to Figure 9) The performance at a 280 millisecond is as good or better than the 1 second performance earlier (Figure 9), while the 280 millisecond display performance is reminiscent of

Figure 13 Results of alphabetic display training analyzed for a trials effect across blocks within a session. The 756 trials were collapsed into four blocks of 65 trials each. Plotted are the precent correct responses per 64 trial block as a function of display time (2 seconds, 1 second, 280 milliseconds and 280 milliseconds preceeded by a warning light).


100
75
50
25
0
% CORRECT
2 sec.
1 sec.
280 w
280 msec.
1
2
3
4
BLOCKS OF 64 TRIALS

the late trial dimunition of Figure 9. It is quite clear that the subject shows significant performance in that reaction times approach limits of human visual-reaction performance (see below).

One of the goals of this project is the training of "automatic" or nearly reflex responding and encoding in human subjects. To this end we are decreasing the display time for this subject to the lower limits of human visual-motor reaction times.

There are two main goals of this type of training. The first is to train subjects to make all responses for a given code nearly in unison ($\pm$ 50 milliseconds). The second is to minimize the time available for discrimination and response selection thereby forcing near automatic responding. Table 1 shows the response latency by muscle for each letter averaged over three sessions with a 280 msec display time.

TABLE I

POOLED OVERALL LATENCIES
IN MILLISECONDS

	Left LL Minimi	Left LT Brevis	Right RT Brevis	Right RL Minimi
A		235		
C	220.8		228.9	
D	201.	198.2	197.8	210.4
E			214	
H	220.4	235.7	231.4	
I				213.8
L		205.4		226.8
M	224.5	241.0		258.7
N	224.6			
O		220.2	227.5	
P	207.7		222.6	205.75
R	226.7	212.9		
S			213.5	232
T	198.3			207.2
U		218.3	222.1	225.2

Reaction latencies seem to be shorter for combinations of muscle responses as opposed to single muscle responses. This reflects the physiological control exerted by motor cortex on flexor motor neurons activating the muscles in question.

PERMANENT SUBJECT TWO

Figures 14, 15 and 16 deal with permanent subject two's performance during three portions of training. Figure 14 reflects patterned light performance for each light pattern (Appendix A) at a 2-second display time for several sessions. There are clear learning curves associated with each pattern and by the third session performance was above 90% controversal. Figure 15 shows performance during the transition from patterned light to alphabetic encoding. There were four sessions during which the subject was presented both patterned light and alphabetic displays. Again, by the third session this subject was performing in excess of 90% correct overall.

The subject was then trained on alphabetic displays only. Figure 16 reflects performance by letter during the first four sessions of letter training at a 2 second display time. Over the sessions, the subject shows consistent improvement and is responding at 90% accuracy by the fourth session. Figure 17 shows a trials effect analysis for two display times for this subject. One curve is for a second display period the other is for a one second period.

These data reflect performance after essentially six days of alphabetic training, four days at 2 seconds and two days at 1 second. At a 2 second display the performance is asymptotic during the session. The more difficult, at this stage of training, one second display response task is indicated by a 60 to 80% performance level. One expects that this performance level will improve also in accord with the other long term subject's performances.

Figure 14 Results of seven daily sessions of lamp display match-to-sample training. Plotted are the sixteen response combinations and overall performance in percent correct. Display time is 2 seconds. The alphabetic characters permit comparison between this and subsequent graphs.

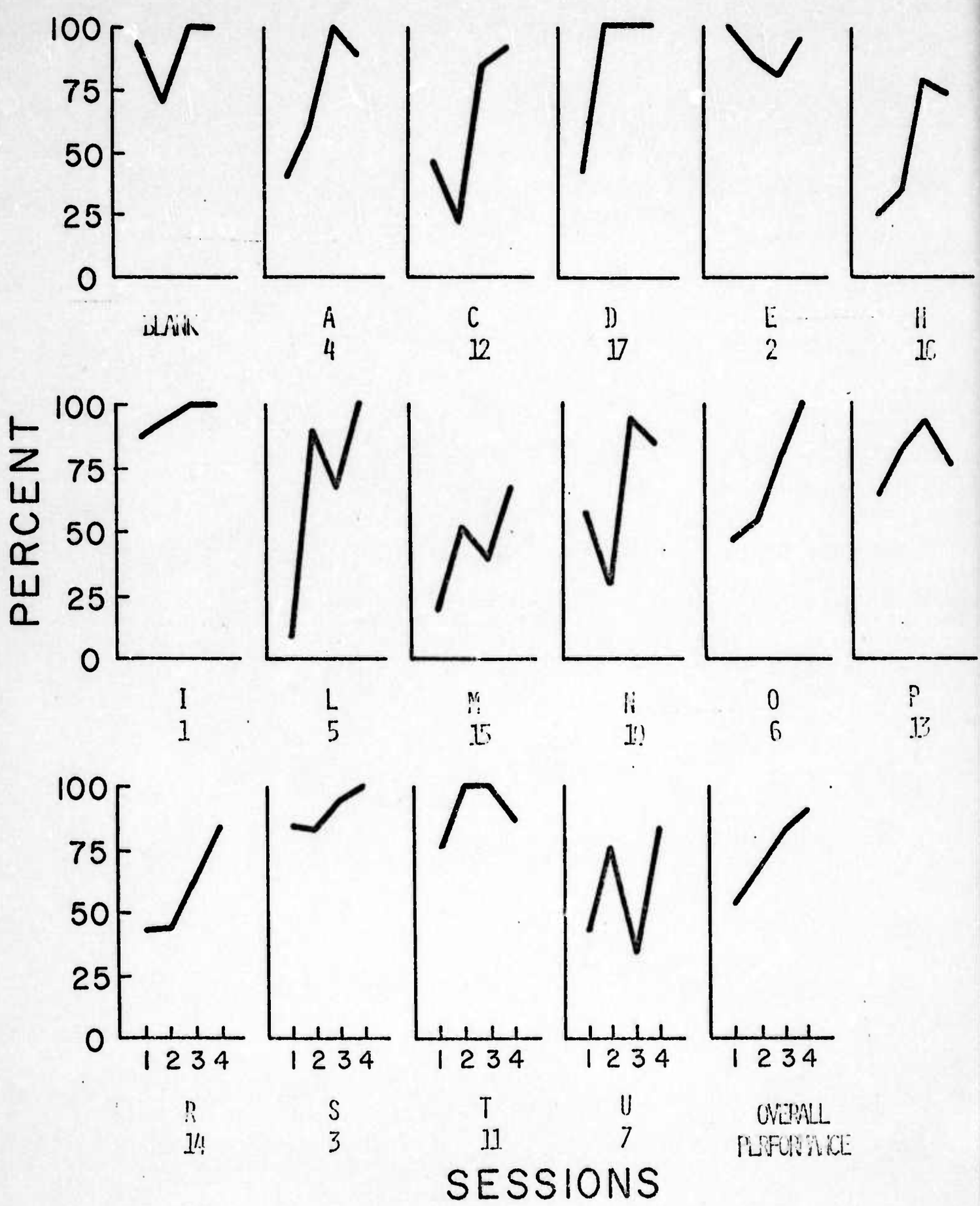

100
75
50
25
0
PERCENT
BLANK
A
4
C
12
D
17
E
2
H
16
I
1
L
5
M
15
N
19
O
6
P
13
R
14
S
3
T
11
U
7
OVERALL PERFORMANCE
1 2 3 4
SESSIONS

Figure 15 Results of four daily sessions of lamp match-to-sample in conjunction with alphabetic training. Plotted are the sixteen alphabetic responses and overall performance. Display time is 2 seconds.

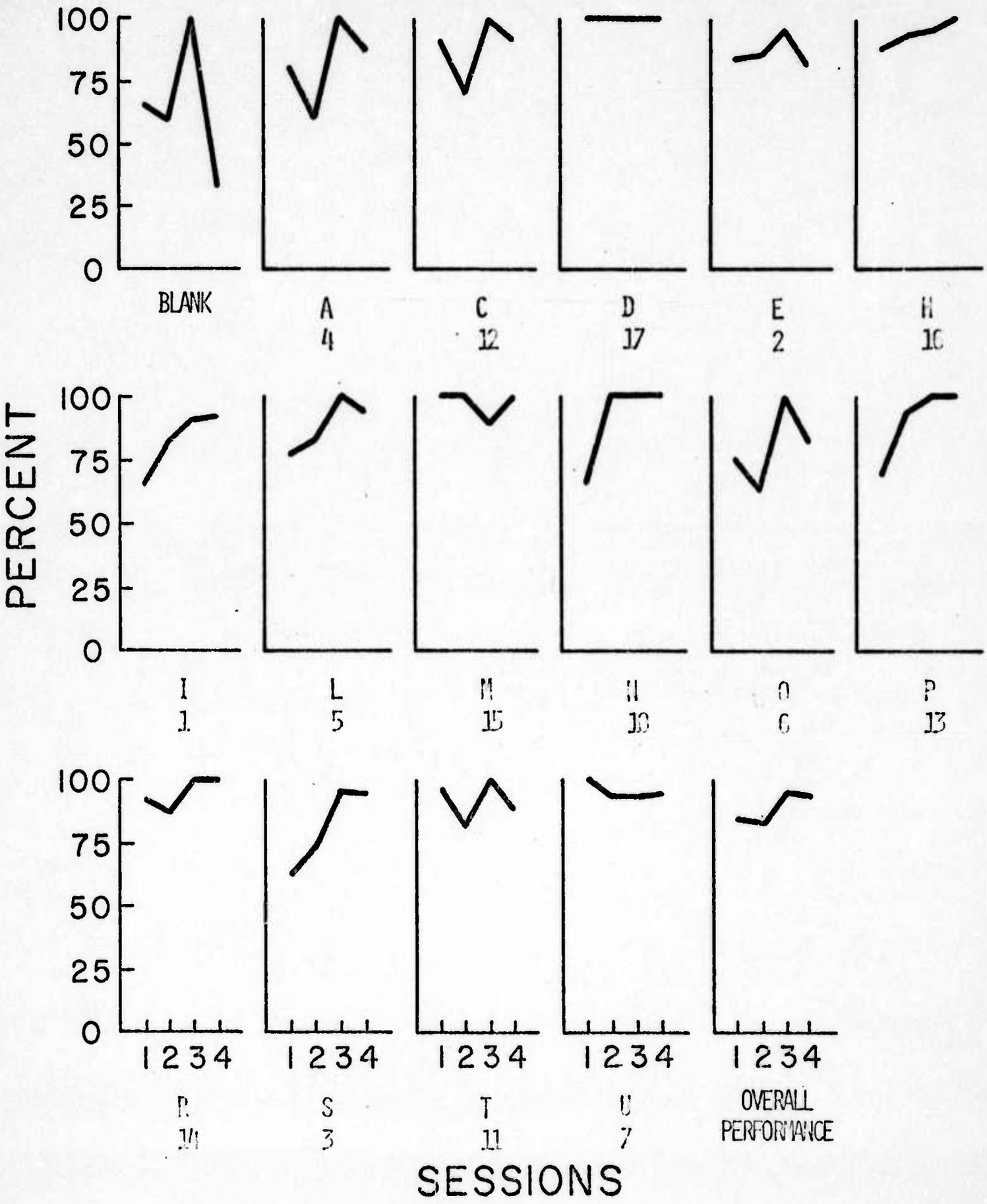

100
75
50
25
0
PERCENT
BLANK
A
4
C
12
D
17
E
2
H
10
I
1
L
5
M
15
N
10
O
6
P
13
R
14
S
3
T
11
U
7
1 2 3 4
OVERALL
PERFORMANCE
SESSIONS

Figure 16 Results for alphabetic training from seven daily sessions of 256 trials each. Plotted are the sixteen alphabetic responses and the overall performance in percent correct responses.
Display time here is 2 seconds.

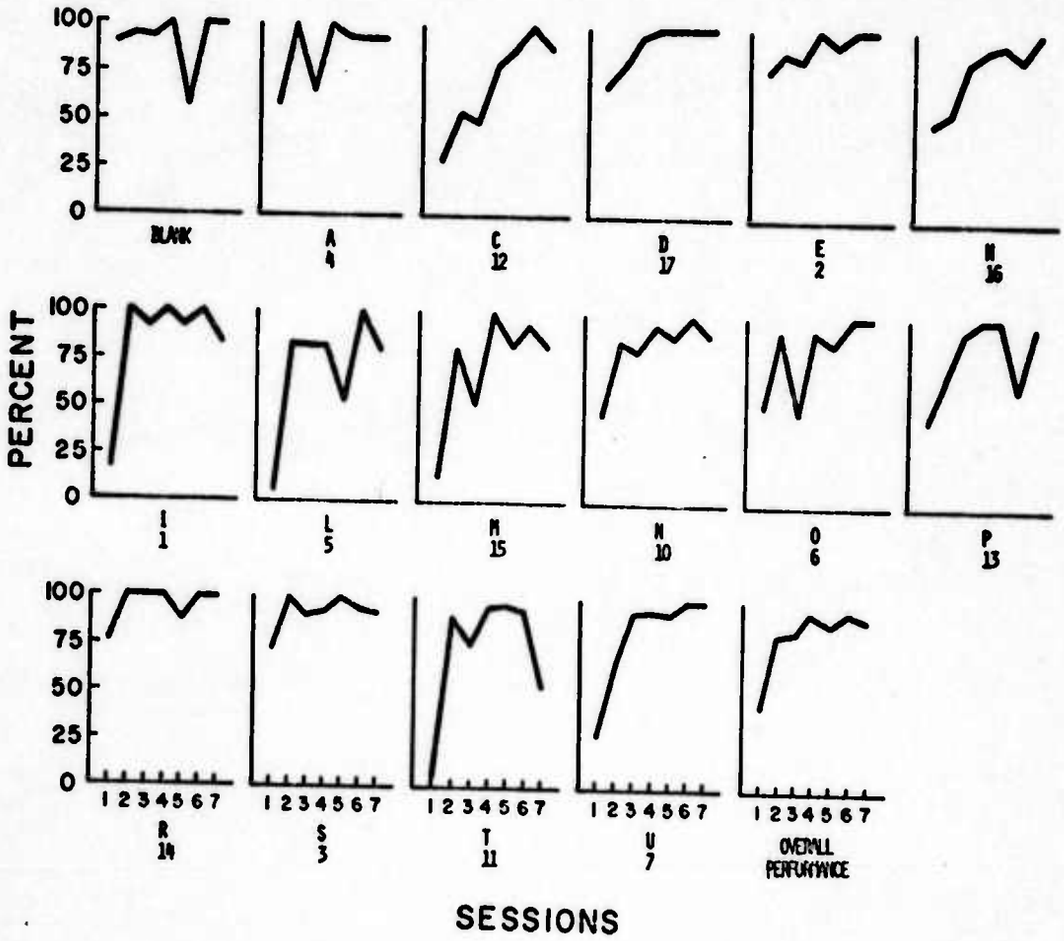
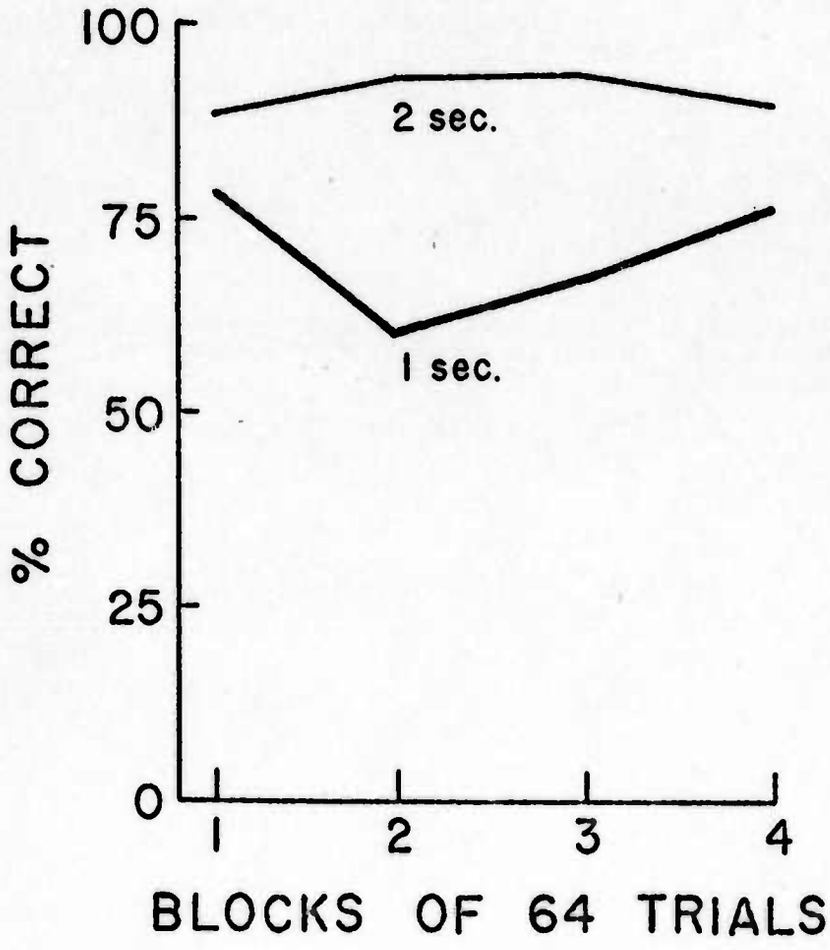

PERCENT
100
75
50
25
0
BLANK
A 4
C 12
D 17
E 2
H 16
I 1
L 5
M 15
N 10
O 6
P 13
R 14
S 3
T 11
U 7
OVERALL PERFORMANCE
1 2 3 4 5 6 7
SESSIONS

Figure 17 Results of alphabetic display training analyzed for a trials effect across blocks within a session. The 256 trials were collapsed into four blocks of 65 trials each. Plotted are the percent correct responses per 64 trial block as a function of display time (2 seconds, 1 second).


100
75
50
25
0
% CORRECT
2 sec.
1 sec.
1
2
3
4
BLOCKS OF 64 TRIALS

BIOFEEDBACK STUDY

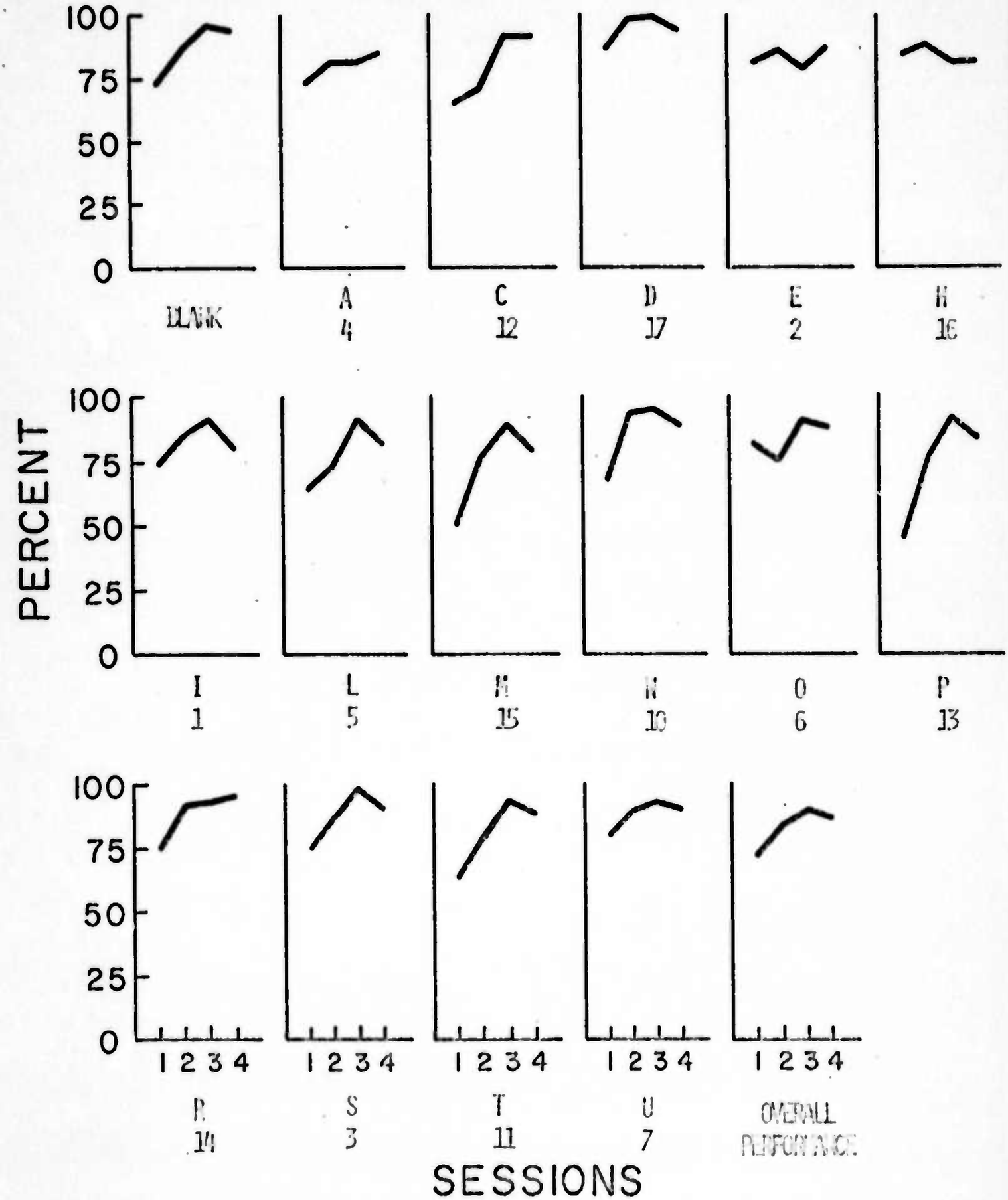
The project is designed to detect bioelectrical analysis of cognitive processes and to use these analogs in control and/or communication of external devices. One facet of this problem deals with the training of humans to use these analogs effectively. It is, therefore, necessary to assess training techniques to maximize the subject's performance through training. Most important is an understanding of what role information feedback derived from these analogs serves in task learning.

To address this issue we have run a multi-subject study in two parts. The first part provides auditory and visual biofeedback during the patterned light phase of training. The second part of the study is the alphabetic training procedure previously discussed.

The paradigm followed consists of four consecutive daily sessions with 256 trials of patterned light training and then four more consecutive daily sessions with 256 trials of alphabetic training with no patterned lights, either S or R Codes. During this study the display lights are presented for 1.5 seconds. Appendix E has the instructions which the subjects read prior to the first session.

Figure 18 shows the results of the patterned light training over the four sessions. These curves represent the averaged results from five subjects in terms of percent correct responses by pattern per session. Note that both the octal code of the pattern and the alphabetic assignment of that pattern are shown. This is to facilitate

Figure 18 Average performance for five subjects to light display match-to-sample by pattern for four sessions. Plotted are the sixteen response combinations and overall performance in percent correct.
Display time is 2 seconds.

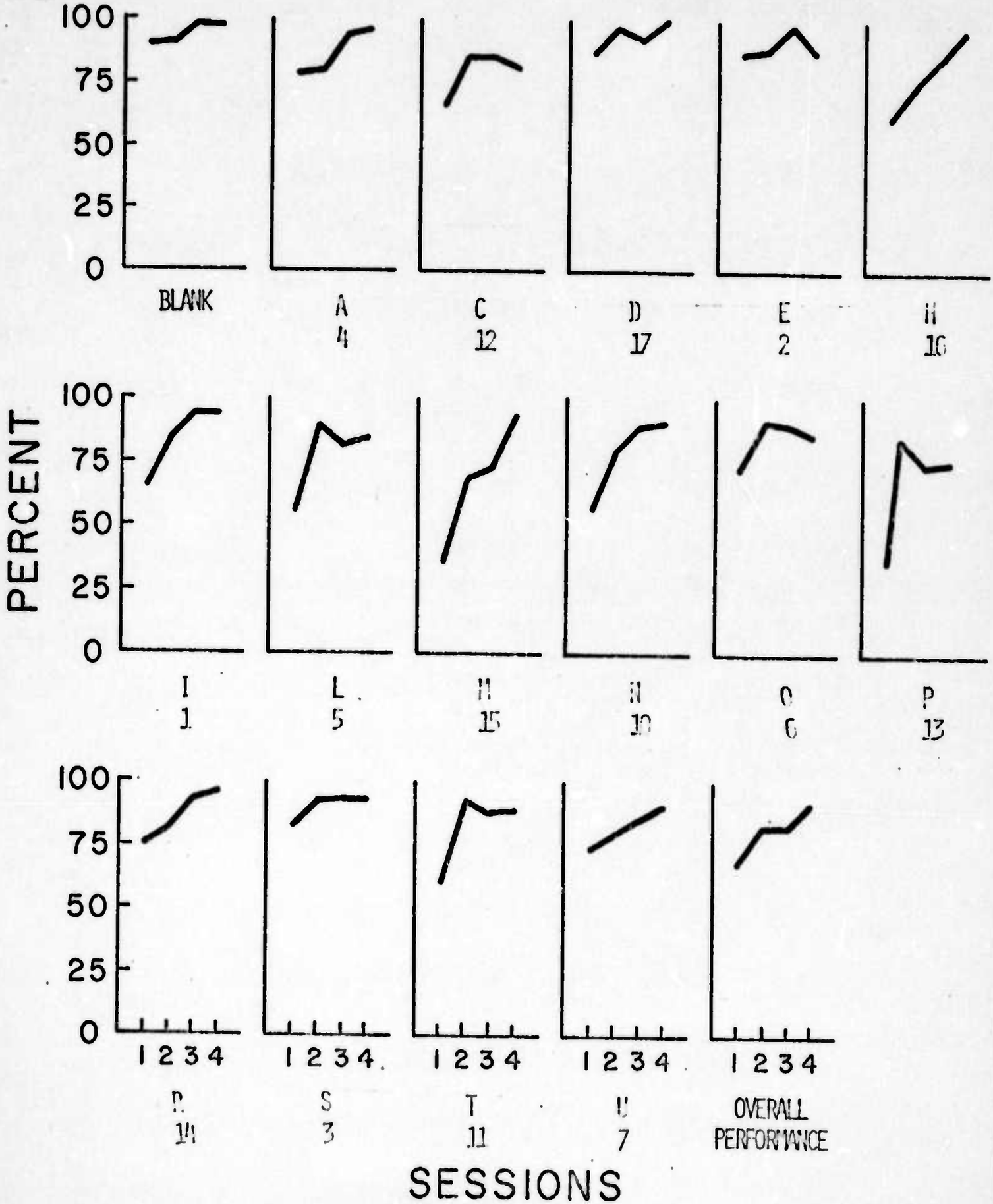

100
75
50
25
0
PERCENT
BLANK
A
4
C
12
D
17
E
2
H
16
I
1
L
5
M
15
N
10
O
6
P
13
R
14
S
3
T
11
U
7
OVERALL
PERFORMANCE
1 2 3 4
SESSIONS

comparison of patterned light training and alphabetic training results discussed below. At the end of the fourth session response accuracy to all patterns is 80% or above. The latency of EMG responses ranges 300 to 700 milliseconds during session four.

Figure 19 shows the averaged results of alphabetic training for four sessions. In this case response accuracy is above 80% in all but the responses to the letter "P" (76%). The latency for EMG response in this case ranges from 300 to 1000 milliseconds during session four.

It is clear that feedback enhances problem solving performance. However, a distinction must be made between problem solving and performance acquisition. The results here are very promising in terms of our training paradigm. However, before a more conclusive estimate of the paradigm's effectiveness can be made, we must run several control groups with varying degrees of training feedback. These groups will be run during the second year. It is clear that with these procedures subjects quickly learn to make the appropriate response.

Figure 19 Average performance for five subjects to alphabetic training for four sessions. Plotted are percent correct for overall performance and by letter. Display time is 2 seconds.


100
75
50
25
0
PERCENT
BLANK
A
4
C
12
D
17
E
2
H
16
I
1
L
5
M
15
N
10
O
0
P
13
R
14
S
3
T
11
U
7
OVERALL
PERFORMANCE
1 2 3 4
SESSIONS

Conclusions

The original contract objectives for the first year were met in nine months elapsed time. Results of this year's effort provide a basic framework for accomplishing the subsequent year's tasks.

There are two essential objectives reached during the time period covered by this report. First, the training procedures we have devised have been validated. Second, the instrumentation and software development to support the project is well advanced and provides the capability to accomplish the objectives defined for subsequent years.

References

Hefferline, R. F. & Perera, T. B. Proprioceptive discrimination of of a covert operant without its observation by the subject. Science, 1963, 139, 834-835.

Leuba, C. & Dunlap, R. Conditioning imagery. J. exp Psychol., 1951, 41, 352-355.

Appendix A

Below are the S Codes and their corresponding alphanumerics. The codes were devised with the following considerations in mind. First it was thought to be desirable to give the most commonly occurring alphabetic characters the simplest code. Thus the letter E received a simple code: the right brevis alone. Since we have 15 codes to issue we determined the 15 most frequent letters and tested them for intelligibility. The 15 letters below comprise a high percentage of those letters actually used in normal communication and can convey a good deal of information.

The codes are given octal representation merely as a convenience.

Alphabetic Character	Left Minimi 4	Left Brevis 3	Right Brevis 2	Right Minimi 1	Binary Code	Octal Code
E			X		0010	02
A		X			0100	04
I				X	0001	01
N	X				1000	10
O		X	X		0110	06
R	X	X			1100	14
S			X	X	0011	03
T	X			X	1001	11
L		X		X	0101	05
C	X		X		1010	12
U		X	X	X	0111	07
P	X		X	X	1011	13
M	X	X		X	1101	15
H	X	X	X		1110	16
D	X	X	X	X	1111	17

The Xs indicate which of the lamps are to be lit for a given alphabetic character.

APPENDIX B

PROGRAM NAME: ARPA 1

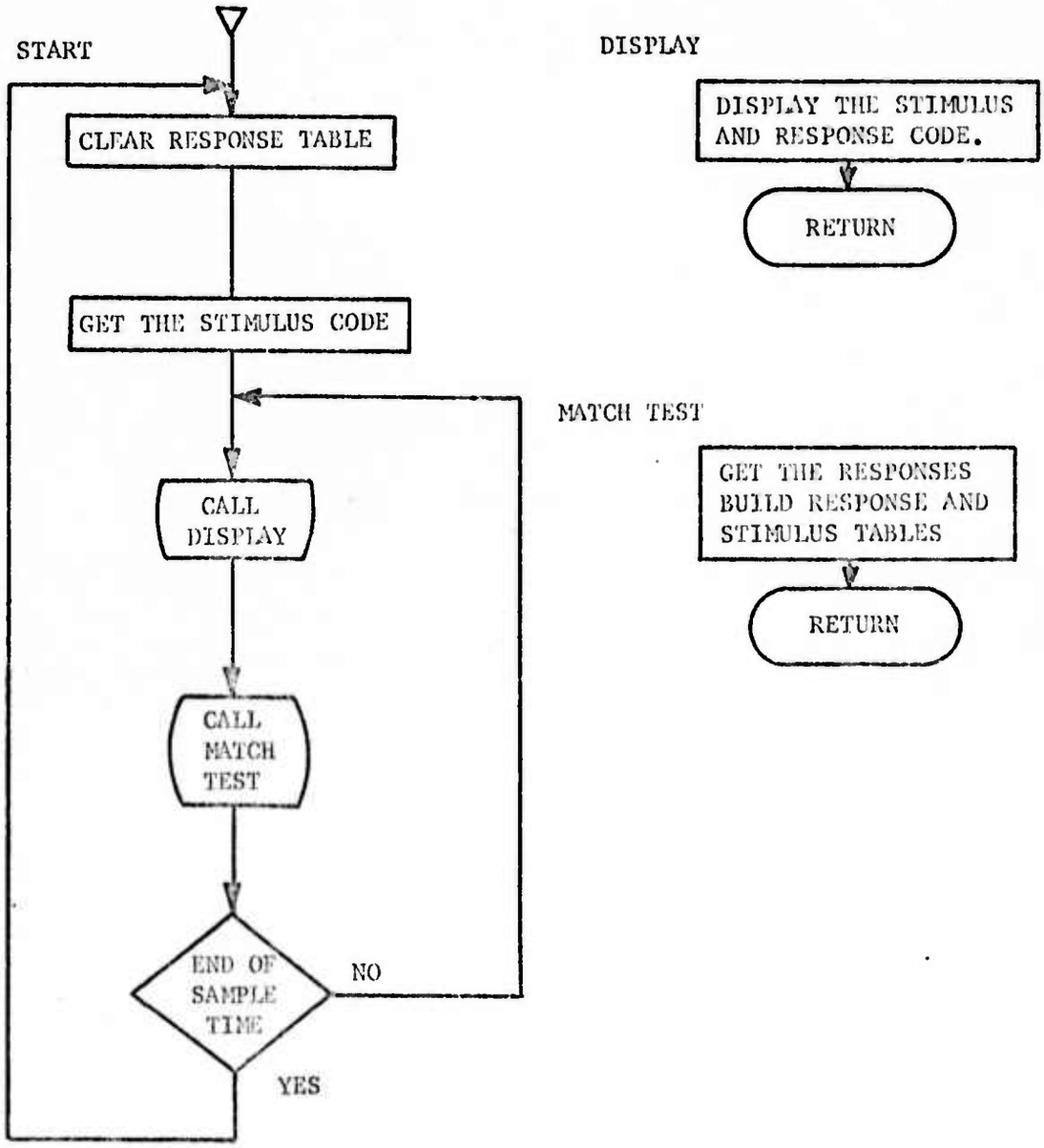
FUNCTION: This program displays two alpha numeric characters. The top character is the "S Code" or stimulus code, the bottom character is the "R Code" or response code.

LANGUAGE: DIAL-LAP6 (ASSEMBLY)

DESCRIPTION: The S Code is accepted from a teletype entry, or, if sense switch 5 is depressed, from the logic levels of external sense lines 5, 6, 7, 10, and 11. In the latter case, a zero volt level to sense line 12 indicates codification of lines 5-11 is complete and sampling may begin.

Simultaneously with displaying the alphanumeric symbol related to the S code, the program monitors external sense lines Ø, 1, 2, 3 and 4 for a corresponding R code. If a match is detected relay KO is set, indicating reinforcement.

ARPA 1 FLOWCHART



```
0000                        *20
0001                              KSF=6031
0002                              KRB=6036
0003                              TSF=6041
0004                              TLS=6046
0005      0020  0011  AASTRT,     CLR
0006      0021  0500              IOB
0007      0022  6046              TLS
0010      0023  0062              SET I 2
0011      0024  0312              HITTBL-1
0012      0025  0063              SET I 3
0013      0026  7767              -10
0014      0027  1062              STA I 2
0015      0030  0223              XSK I 3
0016      0031  6027              JMP .-2          /CLEAR HITTBL
0017      0032  0062              SET I 2
0020      0033  0302              DSCTBL-1
0021      0034  0063              SET I 3
0022      0035  7767              -10
0023      0036  1062              STA I 2
0024      0037  0223              XSK I 3
0025      0040  6036              JMP .-2          /CLEAR DSCTBL
0026      0041  0077              SET I 17
0027      0042  0302              DSCTBL-1
0030      0043  0075              SET I 15
0031      0044  7776  N,          -1
0032      0045  6147              JMP GETCHR
0033      0046  0067              SET I 7
0034      0047  7775  AAA,        -2
0035      0050  6054              JMP THIS
0036      0051  0227              XSK I 7
0037      0052  6050              JMP .-2
0040      0053  6020              JMP AASTRT
0041                        /
0042      0054  1000  THIS,       LDA
0043      0055  0000              0
0044      0056  4071              STC THISR
0045      0057  0066              SET I 6
0046      0060  0000              0
0047      0061  6250              JMP DISIT
0050      0062  0052              SET 12
0051      0063  0044              N
0052      0064  0076              SET I 16
0053      0065  0312              HITTBL-1
0054      0066  6072              JMP MATCHT
0055      0067  0226              XSK I 6
0056      0070  6061              JMP .-7
0057      0071  0000  THISR,      0
0060                        /
0061                        /
0062                        /SAMPLE SENSELINE
0063      0072  1000  MATCHT,     LDA
0064      0073  0000              0
0065      0074  4146              STC MTCHR
0066      0075  0011              CLR
0067      0076  1060              STA I
0070      0077  0000  SUM,        0
0071      0100  0070              SET I 10
0072      0101  0077              SUM
0073      0102  1020              LDA I
0074      0103  0001              1
```

```
0076    0105  1150          ADM 10
0077    0106  1020          LDA I
0100    0107  0002          2
0101    0110  0401          SXL 1
0102    0111  1150          ADM 10
0103    0112  1020          LDA I
0104    0113  0004          4
0105    0114  0402          SXL 2
0106    0115  1150          ADM 10
0107    0116  1020          LDA I
0110    0117  0010          10
0111    0120  0403          SXL 3
0112    0121  1150          ADM 10
0113    0122  6250          JMP DISIT       /REFRESH
0114    0123  1020          LDA I
0115    0124  0425          SNSCOD
0116    0125  2077          ADD SUM
0117    0126  4003          STC 3
0120    0127  1003          LDA 3           /GET ASCII
0121    0130  1560          BCL I
0122    0131  7700          7700
0123    0132  0241          ROL 1
0124    0133  1120          ADA I
0125    0134  0323          CHRDIS
0126    0135  1040          STA
0127    0136  0003          3
0130    0137  1003          LDA 3           /
0131    0140  1076          STA I 16
0132    0141  1023          LDA I 3
0133    0142  1076          STA I 16        /NEW HITS
0134    0143  6250          JMP DISIT
0135    0144  0232          XSK I 12
0136    0145  6075          JMP SUM-2
0137    0146  0000  MTCHR,   0               /MATCH RET
0140                /
0141    0147  1000  GETCHR,  LDA
0142    0150  0000          0
0143    0151  4177          STC CHRRET
0144    0152  0465          SNS I 5
0145    0153  6200          JMP SENSIT
0146    0154  0500          IOB
0147    0155  6031          KSF
0150    0156  6154          JMP .-2
0151    0157  0500          IOB
0152    0160  6036          KRB
0153    0161  1060  STRIP,  STA I
0154    0162  0000  CHAR,    0
0155    0163  1560          BCL I
0156    0164  7700          7700
0157    0165  0241          ROL 1
0160    0166  1120          ADA I
0161    0167  0323          CHRDIS
0162    0170  4003          STC 3
0163    0171  1003          LDA 3
0164    0172  1077          STA I 17
0165    0173  1023          LDA I 3
0166    0174  1077          STA I 17
0167    0175  0235          XSK I 15
0170    0176  6152          JMP GETCHR+3    /MORE WORDS
0171    0177  0000  CHRRET,  0               /GO BACK
0172    0200  0211  SENSIT,  CLR
0173    0201  0432          SXL I 12        /WAIT FOR OK TO SAMPLE
0174    0202  6201          JMP .-1
```

```
0175    0203  1060          STA I
0176    0204  0000  MATCH,  0
0177    0205  0070          SET I 10
0200    0206  0204          MATCH
0201    0207  1020          LDA I
0202    0210  0001          1
0203    0211  0405          SXL 5
0204    0212  1150          ADM 10
0205    0213  1020          LDA I
0206    0214  0002          2
0207    0215  0406          SXL 6
0210    0216  1150          ADM 10
0211    0217  1020          LDA I
0212    0220  0004          4
0213    0221  0407          SXL 7
0214    0222  1150          ADM 10
0215    0223  1020          LDA I
0216    0224  0010          10
0217    0225  0410          SXL 10
0220    0226  1150          ADM 10
0221    0227  1020          LDA I
0222    0230  0020          20
0223    0231  0411          SXL 11
0224    0232  1150          ADM 10
0225    0233  6250          JMP DISIT
0226    0234  1020          LDA I
0227    0235  0425          SNSCOD
0230    0236  2204          ADD MATCH
0231    0237  4003          STC 3
0232    0240  1003          LDA 3
0233    0241  6161          JMP STRIP
0234    0242  1020          LDA I
0235    0243  0425          SNSCOD
0236    0244  2204          ADD MATCH
0237    0245  4003          STC 3
0240    0246  1003          LDA 3
0241    0247  6161          JMP STRIP
0242                  /
0243                  /
0244    0250  1000  DISIT,  LDA
0245    0251  0000          0
0246    0252  4302          STC DISRET
0247    0253  0074          SET I 14
0250    0254  0302          DSCTBL-1
0251    0255  0061          SET I 1
0252    0256  0377          377
0253    0257  0063          SET I 3
0254    0260  7774          -3
0255    0261  0011          CLR
0256    0262  1774          DSC I 14
0257    0263  1774          DSC I 14        /BOTH HALVES
0260    0264  0223          XSK I 3
0261    0265  0261          JMP .-4
0262    0266  0073          SET I 13
0263    0267  0312          HITTBL-1
0264    0270  0061          SET I 1
0265    0271  0377          377
0266    0272  0063          SET I 3
0267    0273  7774          -3
0270    0274  1020          LDA I
0271    0275  7737          -40
0272    0276  1773          DSC I 13        /HIT
0273    0277  1773          DSC I 13
```

```
0274    0300  0223          XSK I 3
0275    0301  6274          JMP .-5
0276    0302  0000  DISRET, 0
0277                /
0300                /
0301    0303  0000  DSCTBL, 0
0302    0304  0000          0
0303    0305  0000          0
0304    0306  0000          0
0305    0307  0000          0
0306    0310  0000          0
0307    0311  0000          0
0310    0312  0000          0
0311                /
0312    0313  0000  HITTBL, 0
0313    0314  0000          0
0314    0315  0000          0
0315    0316  0000          0
0316    0317  0000          0
0317    0320  0000          0
0320    0321  0000          0
0321    0322  0000          0
0322    0323  4020  CHRDIS, 4020
0323    0324  2055          2055          /?
0324    0325  4477          4477
0325    0326  7744          7744          /A
0326    0327  5177          5177
0327    0330  2651          2651          /B
0330    0331  4136          4136
0331    0332  2241          2241          /C
0332    0333  4177          4177
0333    0334  3641          3641          /D
0334    0335  4577          4577
0335    0336  4145          4145          /E
0336    0337  4477          4477
0337    0340  4044          4044          /F
0340    0341  4136          4136
0341    0342  2645          2645          /G
0342    0343  1077          1077
0343    0344  7710          7710
0344                /H
0345    0345  7741          7741
0346    0346  0041          0041          /I
0347    0347  4142          4142
0350    0350  4072          4072          /J
0351    0351  1077          1077
0352    0352  4324          4324          /K
0353    0353  0177          0177
0354    0354  0301          0301          /L
0355    0355  3077          3077
0356    0356  7730          7730          /M
0357    0357  3077          3077
0360    0360  7706          7706          /N
0361    0361  4177          4177
0362    0362  7741          7741          /O
0363    0363  4477          4477
0364    0364  3044          3044          /P
0365    0365  4276          4276
0366    0366  0376          0376          /Q
0367    0367  4477          4477
0370    0370  3146          3146
0371    0371  5121          5121
0372    0372  4651          4651
```

```
0373    0373  4040          4040
0374    0374  4077          4077          /T
0375    0375  0177          0177
0376    0376  7701          7701          /U
0377    0377  0176          0176
0400    0400  7402          7402          /V
0401    0401  0677          0677
0402    0402  7701          7701          /W
0403    0403  1463          1463
0404    0404  6314          6314          /X
0405    0405  0770          0770
0406    0406  7007          7007          /Y
0407    0407  4543          4543
0410    0410  6151          6151          /Z
0411    0411  0000          0
0412    0412  0000          0
0413    0413  0000          0
0414    0414  0000          0
0415    0415  0000          0
0416    0416  0000          0
0417    0417  0000          0
0420    0420  0000          0
0421    0421  0000          0
0422    0422  0000          0
0423    0423  0000          0
0424    0424  0000          0
0425                  /
0426                  /
0427    0425  0240    SNSCOD, 240
0430    0426  0311            311
0431    0427  0305            305
0432    0430  0323            323
0433    0431  0301            301
0434    0432  0314            314
0435    0433  0317            317
0436    0434  0325            325
0437    0435  0316            316
0440    0436  0324            324
0441    0437  0303            303
0442    0440  0320            320
0443    0441  0322            322
0444    0442  0315            315
0445    0443  0310            310
0446    0444  0304            304
0447                  /
0450    0445  0000    TTYCOD, 0
0451    0446  0004            4             /A
0452    0447  0000            0             /B
0453    0450  0012            12            /C
0454    0451  0017            17            /D
0455    0452  0002            2             /E
0456    0453  0000            0             /F
0457    0454  0000            0             /G
0460    0455  0016            16            /H
0461    0456  0001            1             /I
0462    0457  0000            0             /J
0463    0460  0000            0             /K
0464    0461  0005            5             /L
0465    0462  0015            15            /M
0466    0463  0010            10            /N
0467    0464  0006            6             /O
0470    0465  0013            13            /P
0471    0466  0000            0             /Q
```

```
0472    0467  0014        14          /R
0473    0470  0003        3           /S
0474    0471  0011        11          /T
0475    0472  0007        7           /U
0476    0473  0000        0           /V
0477    0474  0000        0           /W
0500    0475  0000        0           /X
0501    0476  0000        0           /Y
0502    0477  0000        0           /Z
0503                  /
0504                  /ARPA1
0505                  /
0506                  /PROGRAM ACCEPTS STIMULUS CODE FROM
0507                  /EITHER THE TTY (IF SENSE SWITCH 5 IS UP) OR VIA N
                       OCTAL CODE
0510                  /VIA SENSE LINES 5,6,7,10, AND 11
0511                  /(IF SNS 5 IS DOWN). A GROUND TO SXL 12
0512                  /INDICATES THAT SENSE LINE CODIFICATION IS COMPLEE
0513                  /
0514                  /PROGRAM THEN MONITORS THE RESPONSE CODE
0515                  /VIA SXL 0-4 FOR CORRESPONDANCE TO THE S-CODE
0516                  /THE ALPHA EQUIVALENT OF THE S-CODE IS DISPLAYED
0517                  /ON TOP, THE R-CODE IS DISPLAYED ON THE BOTTOM.
0520                  /1-DISIT
0521                  /2- UNUSED
0522                  /3-SCRATCH
0523                  /4-UNUSED
0524                  /5-UNUSED
0525                  /6-DISPLAY TIMER
0526                  /7-DISPLAY TIMER
0527                  /10 SUM AND MATCH POINTER
0530                  /11-UNUSED
0531                  /12- NUMBER OF CHARACTERS
0532                  /13-DISIT R-CODE
0533                  /14-DISIT S-CODE
0534                  /15 NUMBER OF CHARACTERS
0535                  /16-R-CODE
0536                  /17-S-CODE

NO ERRORS

AAA     4047
AASTRT  4020
CHAR    4162
CHRDIS  4323
CHRRET  4177
DISIT   4250
DISRET  4302
DSCTBL  4303
GETCHR  4147
HITTBL  4313
KRB     6036
KSF     6031
MATCH   4204
MATCHT  4072
NTCHR   4146
N       4044
SENSIT  4200
SNSCOD  4425
STRIP   4161
SUM     4077
THIS    4054
THISR   4071
```

```
TLS     6046
TSF     6041
TTYCOD  4445
```

APPENDIX C

PROGRAM NAME: ARPA 6.

FUNCTION: Program displays two alphanumeric characters, determines coincidence of stimulus and response codes, determines latency to respond for each muscle, and provides hard and soft copy read outs of performance.

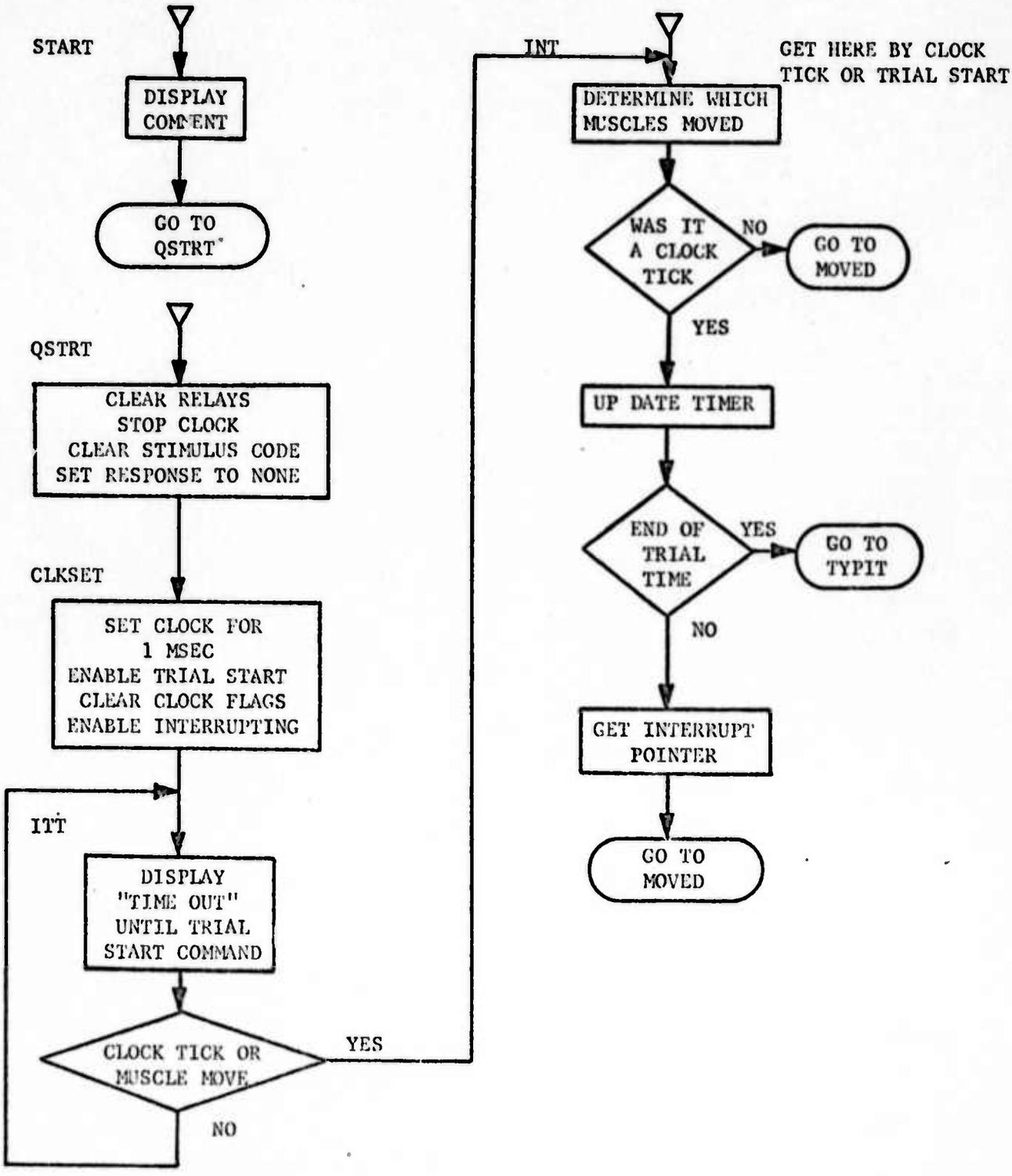
LANGUAGE: DIAL-LAP6 (ASSEMBLY)

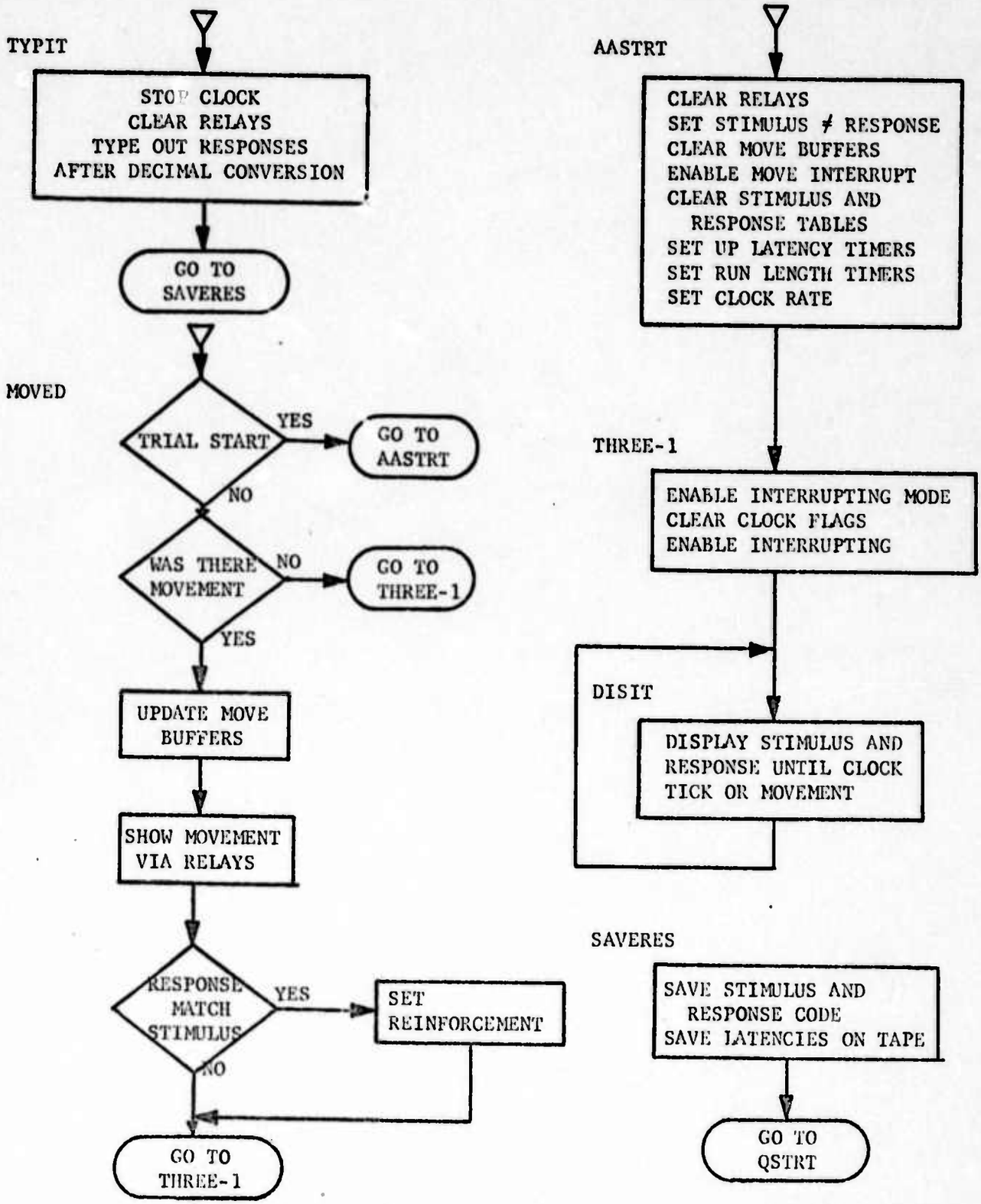
DESCRIPTION: The S code is accepted from a teletype entry, or if sense switch five is up, from external sense lines 5, 6, 7, 10, and 11. In the latter case, a zero volt level to sense line 12 indicates codification is complete and sampling may begin.

Simultaneously with displaying the alphanumeric symbol related to the S code, the program monitors muscle responses. If a muscle movement indication is detected the program scans external sense lines 0, 1, 2, 3, and 4 to determine which muscles were involved. Any movement occurring during the display period is classified as a component of the R code for the current trial. The first detected movement on each sense line stops its respective latency counter.

A trial is initiated by a synchronizing command to clock input #1. At this time the S code is decoded, the run length, or display length, times initialized, the latency times reset, the clock started and the S code displayed.

ARPA 6 FLOWCHART




TYPIT
STOP CLOCK
CLEAR RELAYS
TYPE OUT RESPONSES
AFTER DECIMAL CONVERSION
GO TO
SAVERES
MOVED
TRIAL START
YES
GO TO
AASTRT
NO
WAS THERE
MOVEMENT
NO
GO TO
THREE-1
YES
UPDATE MOVE
BUFFERS
SHOW MOVEMENT
VIA RELAYS
RESPONSE
MATCH
STIMULUS
YES
SET
REINFORCEMENT
NO
GO TO
THREE-1
AASTRT
CLEAR RELAYS
SET STIMULUS ≠ RESPONSE
CLEAR MOVE BUFFERS
ENABLE MOVE INTERRUPT
CLEAR STIMULUS AND
RESPONSE TABLES
SET UP LATENCY TIMERS
SET RUN LENGTH TIMERS
SET CLOCK RATE
THREE-1
ENABLE INTERRUPTING MODE
CLEAR CLOCK FLAGS
ENABLE INTERRUPTING
DISIT
DISPLAY STIMULUS AND
RESPONSE UNTIL CLOCK
TICK OR MOVEMENT
SAVERES
SAVE STIMULUS AND
RESPONSE CODE
SAVE LATENCIES ON TAPE
GO TO
QSTRT

```
0000                        *20
0001                                SEGMNT 0
0002                                *20
0003    0020  0001  ONE,    1
0004    0021  0002  TWO,    2
0005    0022  0004  FOUR,   4
0006    0023  0010  TEN,    10
0007    0024  0020  TWENTY, 20
0010                        *40
0011    0040  0000          0
0012                        KSF=6031
0013                        KRB=6036
0014                        TSF=6041
0015                        TLS=6046
0016    0041  0011  INT,    CLR
0017    0042  1000          LDA
0020    0043  0020          ONE
0021    0044  0400          SXL 0
0022    0045  7055          JMP MOVED0
0023    0046  1000          LDA
0024    0047  0021          TWO
0025    0050  0401          SXL 1
0026    0051  7064          JMP MOVED1
0027    0052  1000          LDA
0030    0053  0022          FOUR
0031    0054  0402          SXL 2
0032    0055  7072          JMP MOVED2
0033    0056  1000          LDA
0034    0057  0023          TEN
0035    0060  0403          SXL 3
0036    0061  7100          JMP MOVED3
0037    0062  1000          LDA
0040    0063  0024          TWENTY
0041    0064  0404          SXL 4
0042    0065  7106          JMP MOVED4
0043    0066  0011          CLR
0044    0067  0500          IOB
0045    0070  6135          CLSA
0046    0071  0471          APO I
0047    0072  6457          JMP MOVED
0050    0073  1060          STA I
0051    0074  0000  RCLSA,  0
0052                        /CLOCK TIMED
0053    0075  0231          XSK I 11        /TIMER
0054    0076  6136          JMP BUFF1-1     /PATCH TO CUT OUT TIMERS
0055    0077  6136          JMP BUFF1-1
0056    0100  6147          JMP TYPIT       /TYPE OUT CHAR,HIT AND RE
                            ACTIONS
0057    0101  0224          XSK I 4
0060    0102  6106          JMP TRY5
0061    0103  4137          STC BUFF1
0062    0104  0044          SET 4
0063    0105  0655          NEG
0064    0106  0225  TRY5,   XSK I 5
0065    0107  6113          JMP TRY6
0066    0110  4132          STC BUFF2
0067    0111  0045          SET 5
0070    0112  0655          NEG
0071    0113  0226  TRY6,   XSK I 6
0072    0114  6120          JMP TRY7
0073    0115  4133          STC BUFF3
0074    0116  0046          SET 6
```

```
0075    0117  0655            NEG
0076    0120  0227  TRY7,     XSK I 7
0077    0121  6125            JMP TRY10
0100    0122  4134            STC BUFF4       /250 MSEC OVER
0101    0123  0047            SET 7
0102    0124  0655            NEG
0103    0125  0230  TRY10,    XSK I 10
0104    0126  6136            JMP BUFF1-1
0105    0127  0050            SET 10
0106    0130  0655            NEG
0107    0131  4135            STC BUFF5
0110    0132  0000  BUFF2,    0
0111    0133  0000  BUFF3,    0
0112    0134  0000  BUFF4,    0
0113    0135  0000  BUFF5,    0
0114    0136  1020            LDA I
0115    0137  0000  BUFF1,    0
0116    0140  0232            XSK I 12        /RUN LENGTH TIMER
0117    0141  0456            SKP
0120    0142  6147            JMP TYPIT
0121    0143  1000            LDA
0122    0144  0074            RCLSA           /TEST FOR MOVEMENT
0123    0145  6457            JMP MOVED
0124    0146  6703            JMP THREE-1
0125                  /
0126    0147  0011  TYPIT,    CLR
0127    0150  0500            IOB
0130    0151  6132            CLLR            /STOP CLOCK
0131    0152  0015            RTA
0132    0153  1560            BCL I
0133    0154  0037            0037
0134    0155  0014            ATR             /CLEAR TRIAL  R RELAYS
0135    0156  0464            SNS I 4
0136    0157  6221            JMP TDONE
0137    0160  0500            IOB
0140    0161  6046            TLS
0141    0162  6247            JMP CRLF
0142    0163  1000  NXT,      LDA
0143    0164  0741            CHAR
0144    0165  6237            JMP PUT
0145    0166  1020            LDA I
0146    0167  0240  SPACE,    240
0147    0170  6237            JMP PUT
0150    0171  1000            LDA
0151    0172  0630            HIT
0152    0173  6237            JMP PUT
0153    0174  1000            LDA
0154    0175  0167            SPACE
0155    0176  6237            JMP PUT
0156    0177  1020            LDA I
0157    0200  0275            275             /=
0160    0201  6237            JMP PUT
0161    0202  1000            LDA
0162    0203  0167            SPACE
0163    0204  6237            JMP PUT
0164    0205  1000            LDA
0165    0206  0004            4
0166    0207  6256            JMP CONVRT
0167    0210  1000            LDA
0170    0211  0005            5
0171    0212  6256            JMP CONVRT
0172    0213  1000            LDA
0173    0214  0006            6
```

```
0174    0215  6256          JMP CONVRT
0175    0216  1000          LDA
0176    0217  0007          7
0177    0220  6256          JMP CONVRT
0200                        /LDA
0201                        /10
0202                        /JMP CONVRT
0203    0221  0602  TDONE,    LIF 2
0204    0222  6101          JMP SAVRES
0205                  /
0206    0223  1000  BLANK,   LDA
0207    0224  0000          0
0210    0225  4236          STC BNKRET
0211    0226  0062          SET I 2
0212    0227  7771          -6
0213    0230  1000          LDA
0214    0231  0167          SPACE
0215    0232  6237          JMP PUT
0216    0233  0222          XSK I 2
0217    0234  6230          JMP .-4
0220    0235  6454          JMP RETBIN-2
0221    0236  0000  BNKRET,  0
0222                  /
0223                  /
0224    0237  0041  PUT,     SET 1
0225    0240  0000          0
0226    0241  0500          IOB
0227    0242  6041          TSF
0230    0243  6241          JMP .-2
0231    0244  0500          IOB
0232    0245  6046          TLS
0233    0246  6001          JMP 1
0234                  /
0235    0247  1020  CRLF,    LDA I
0236    0250  0215          215
0237    0251  6237          JMP PUT
0240    0252  1020          LDA I
0241    0253  0212          212
0242    0254  6237          JMP PUT
0243    0255  6163          JMP NXT
0244                  /
0245    0256  4301  CONVRT,  STC VAR
0246    0257  1000          LDA
0247    0260  0000          0
0250    0261  4456          STC RETBIN
0251    0262  1000          LDA
0252    0263  0301          VAR
0253    0264  1460          SAE I
0254    0265  7777          7777
0255    0266  0456          SKP
0256    0267  6223          JMP BLANK       /TYPE BLANKS IF 4093
0257    0270  0077          SET I 17
0260    0271  7765          -12
0261    0272  0076          SET I 16
0262    0273  7765          -12
0263    0274  0075          SET I 15
0264    0275  7765          -12
0265    0276  0074          SET I 14
0266    0277  7765          -12
0267    0300  1020          LDA I
0270    0301  0000  VAR,     0
0271    0302  0471          APO I
0272    0303  6352          JMP K1024
```

```
0273    0304  0241          ROL 1
0274    0305  0451          APO
0275    0306  6331          JMP K3072
0276    0307  1000          LDA
0277    0310  0301          VAR
0300    0311  1560          BCL I
0301    0312  4000          4000
0302    0313  4301          STC VAR
0303    0314  1020          LDA I
0304    0315  0011          11
0305    0316  1140          ADM
0306    0317  0017          17
0307    0320  1020          LDA I
0310    0321  0004          4
0311    0322  1140          ADM
0312    0323  0016          16
0313    0324  1020          LDA I
0314    0325  0002          2
0315    0326  1140          ADM
0316    0327  0014          14
0317    0330  6372          JMP CONV-6
0320                  /
0321    0331  1020  K3072,   LDA I
0322    0332  0002          2
0323    0333  1157          ADM 17
0324    0334  1020          LDA I
0325    0335  0007          7
0326    0336  1140          ADM
0327    0337  0016          16
0330    0340  1020          LDA I
0331    0341  0003          3
0332    0342  1140          ADM
0333    0343  0014          14
0334    0344  1000          LDA
0335    0345  0301          VAR
0336    0346  1560          BCL I
0337    0347  4000          4000
0340    0350  4301          STC VAR
0341    0351  6372          JMP CONV-6
0342                  /
0343    0352  0241  K1024,   ROL 1
0344    0353  0471          APO I
0345    0354  6372          JMP CONV-6
0346    0355  1020          LDA I
0347    0356  0004          4
0350    0357  1140          ADM
0351    0360  0017          17
0352    0361  1020          LDA I
0353    0362  0002          2
0354    0363  1140          ADM
0355    0364  0016          16
0356    0365  1020          LDA I
0357    0366  0001          1
0360    0367  1140          ADM
0361    0370  0014          14
0362    0371  6372          JMP CONV-6
0363                  /
0364    0372  1000          LDA
0365    0373  0301          VAR
0366    0374  1120          ADA I
0367    0375  0001          1
0370    0376  0017          COM
0371    0377  4003          STC 3
```

```
0372    0400  0223  CONV,   XSK I 3
0373    0401  0456          SKP
0374    0402  6422          JMP CNVCMP
0375    0403  0237          XSK I 17
0376    0404  6400          JMP CONV
0377    0405  0077          SET I 17
0400    0406  7765          -12
0401    0407  0236          XSK I 16
0402    0410  6400          JMP CONV
0403    0411  0076          SET I 16
0404    0412  7765          -12
0405    0413  0235          XSK I 15
0406    0414  6400          JMP CONV
0407    0415  0075          SET I 15
0410    0416  7765          -12
0411    0417  0234          XSK I 14
0412    0420  6400          JMP CONV
0413    0421  6400          JMP CONV
0414                  /
0415    0422  1000  CNVCMP, LDA
0416    0423  0014          14
0417    0424  1120          ADA I
0420    0425  0272  MINUS1, 272
0421    0426  6237          JMP PUT
0422    0427  1000          LDA
0423    0430  0015          15
0424    0431  1100          ADA
0425    0432  0425          MINUS1
0426    0433  6237          JMP PUT
0427    0434  1000          LDA
0430    0435  0016          16
0431    0436  1100          ADA
0432    0437  0425          MINUS1
0433    0440  6237          JMP PUT
0434    0441  1000          LDA
0435    0442  0017          17
0436    0443  1100          ADA
0437    0444  0425          MINUS1
0440    0445  6237          JMP PUT
0441    0446  1000          LDA
0442    0447  0167          SPACE
0443    0450  6237          JMP PUT
0444    0451  1000          LDA
0445    0452  0167          SPACE
0446    0453  6237          JMP PUT
0447    0454  0500          IOB
0450    0455  6244          RMF
0451    0456  0000  RETBIN, 0                 /RETURN
0452                  /
0453                  RMF=6244
0454                  /SHOW MOVEMENT BY RELAY AND SET CAPTURE
0455                  /TIMER IF NO MOVEMENT BEFORE
0456    0457  0246  MOVED,  ROL 6             /EVENT 1?
0457    0460  0471          APO I
0460    0461  0456          SKP
0461    0462  6543          JMP TRLSRT        /YES
0462    0463  0244          ROL 4             /EVENT 3
0463    0464  0471          APO I
0464    0465  6703          JMP THREE-1
0465    0466  1060          LDA
0466    0467  0137          BUFF1
0467    0470  2132          ADD BUFF2
0470    0471  2133          ADD BUFF3
```

```
0471    0472  2134          ADD BUFF4
0472    0473  2135          ADD BUFF5
0473    0474  1060          STA I
0474    0475  0000  RRTEMP, 0
0475    0476  0015          RTA
0476    0477  1560          BCL I
0477    0500  0037          37
0500    0501  1600          BSE
0501    0502  0475          RRTEMP
0502    0503  0014          ATR              /SHOW MOVEMENT
0503    0504  0643          LDF 3
0504    0505  1020          LDA I
0505    0506  2122          SNSCOD!2000
0506    0507  1100          ADA
0507    0510  0475          RRTEMP
0510    0511  4003          STC 3
0511    0512  1003          LDA 3
0512    0513  1040          STA
0513    0514  0630          HIT
0514    0515  1560          BCL I
0515    0516  7700          7700
0516    0517  0241          ROL 1
0517    0520  1120          ADA I
0520    0521  2020          CHRDIS!2000
0521    0522  4003          STC 3
0522    0523  1003          LDA 3
0523    0524  0076          SET I 16
0524    0525  2007          HITTBL-1!2000
0525    0526  1076          STA I 16
0526    0527  1023          LDA I 3
0527    0530  1076          STA I 16
0530    0531  1000          LDA
0531    0532  0741          CHAR
0532    0533  1440          SAE
0533    0534  0630          HIT
0534    0535  6703          JMP THREE-1
0535    0536  0015          RTA
0536    0537  1620          BSE I
0537    0540  0040          0040
0540    0541  0014          ATR              /SET REINFORCEMENT
0541    0542  6703          JMP THREE-1
0542                  /
0543    0543  6615  TRLSRT, JMP AASTRT
0544                  /
0545    0544  1020  ERRORS, LDA I
0546    0545  0277          277
0547    0546  6237          JMP PUT
0550    0547  0063          SET I 3
0551    0550  7774          -3
0552    0551  1020          LDA I
0553    0552  0207          207
0554    0553  6237          JMP PUT
0555    0554  0223          XSK I 3
0556    0555  6551          JMP .-4
0557    0556  0000          HLT
0560                  /
0561                  /START OF MAIN FROM GUANDA IN LF 2
0562    0557  0011  QSTRT,  CLR
0563    0560  0014          ATR              /CLEAR RELAYS
0564    0561  0011          CLR
0565    0562  0000          IOS
0566    0563  6132          CLLR             /STOP CLOCK
0567    0564  0016          NOP/SET I 17
```

```
0570    0565  0016          NOP/3777
0571    0566  0016          NOP/LDF 4
0572    0567  0016          NOP/STA I 17
0573    0570  0016          NOP/XSK 17
0574    0571  0016          NOP/JMP .-2              /CLR STORAGE
0575    0572  4741          STC CHAR
0576    0573  1020          LDA I
0577    0574  0243  K243,    243
0600    0575  4630          STC HIT
0601    0576  1020  CLKSET,  LDA I
0602    0577  7776  TIME,    7776     / 1 MSEC TICK
0603    0600  0500          IOB
0604    0601  6133          CLAB
0605    0602  1020          LDA I
0606    0603  0060          60                  /ENABLE INPUT 1
0607    0604  0500          IOB
0610    0605  6134          CLEN
0611    0606  0500          IOB
0612    0607  6135          CLSA                /CLR FLAG
0613    0610  0500          IOB
0614    0611  6001          ION
0615    0612  0602          LIF 2
0616    0613  6057          JMP ITI             /DISPLAY ITICOMMNENT
0617    0614  6614          JMP .               /WAIT FOR TRIAL START
0620    0615  0011  AASTRT,  CLR
0621    0616  0015          RTA
0622    0617  1560          BCL I
0623    0620  0037          0037
0624    0621  0014          ATR
0625    0622  1020          LDA I
0626    0623  0244  K244,    244
0627    0624  4741          STC CHAR
0630    0625  1000          LDA
0631    0626  0574          K243
0632    0627  1060          STA I
0633    0630  0000  HIT,     0
0634    0631  1020          LDA I
0635    0632  0103          103
0636    0633  4704          STC THREE           /SET INT FOR EVENT 3
0637    0634  4137          STC BUFF1
0640    0635  4132          STC BUFF2
0641    0636  4133          STC BUFF3
0642    0637  4134          STC BUFF4
0643    0640  4135          STC BUFF5
0644    0641  0643          LDF 3
0645    0642  0062          SET I 2
0646    0643  7776          DSCTBL-1!2000
0647    0644  0063          SET I 3
0650    0645  7767          -10
0651    0646  0064          SET I 4
0652    0647  2007          HITTBL-1!2000
0653    0650  1062          STA I 2
0654    0651  1064          STA I 4
0655    0652  0223          XSK I 3
0656    0653  6651          JMP .-2             /CLEAR DSCTBL
0657    0654  0075          SET I 15
0660    0655  7776  NEG,     -1
0661    0656  0077          SET I 17
0662    0657  7776          DSCTBL-1!2000
0663    0660  6717          JMP GETCHR          /CHANGE CHAR
0664                  /
0665    0661  0064          SET I 4
0666    0662  7777          7777
```

```
0667    0663  0065          SET I 5
0670    0664  7777          7777
0671    0665  0066          SET I 6
0672    0666  7777          7777
0673    0667  0067          SET I 7
0674    0670  7777          7777
0675    0671  0070          SET I 10
0676    0672  7777          7777
0677    0673  0071          SET I 11
0700    0674  0000          0
0701    0675  0072          SET I 12
0702    0676  6027  SAMTIM, -1750
0703    0677  1020          LDA I
0704    0700  4100          4100            /1KC AND PRESET
0705    0701  0500          IOB
0706    0702  6132          CLLR
0707                        CLAB=6133
0710                        CLLR=6132
0711                        CLEN=6134
0712                        CLSA=6135
0713                        CLSK=6131
0714                        ION=6001
0715                        IOF=6002
0716    0703  1020          LDA I
0717    0704  0103  THREE,  103             /MOVEMENT OR CLOCK
0720    0705  0500          IOB
0721    0706  6134          CLEN            /ENABLE INPUT 3
0722    0707  0500          IOB
0723    0710  6135          CLSA            /CLEAR INTERUPT
0724    0711  1020          LDA I
0725    0712  0240          240
0726    0713  0004          ESF             /LOCK OUT TTY
0727    0714  0500          IOB
0730    0715  6001          ION
0731    0716  7020          JMP DISIT
0732                  /
0733    0717  1000  GETCHR, LDA
0734    0720  0000          0
0735    0721  4756          STC CHRRET
0736    0722  0072          SET I 12
0737    0723  7776          DSCTBL-112000
0740    0724  0070          SET I 10
0741    0725  7767          -10
0742    0726  1072          STA I 12
0743    0727  0230          XSK I 10
0744    0730  6726          JMP .-2
0745    0731  0445          SNS 5
0746    0732  6757          JMP SENSIT
0747    0733  0500          IOB
0750    0734  6031          KSF
0751    0735  6731          JMP .-4
0752    0736  0500          IOB
0753    0737  6036          KRB
0754    0740  1060  STRIP,  STA I
0755    0741  0000  CHAR,   0
0756    0742  1560          DCL I
0757    0743  7700          7700
0760    0744  0041          ROL 1
0761    0745  1120          ADA I
0762    0746  2020          CHRDIS!2000
0763    0747  4003          STC 3
0764    0750  1003          LDA 3
0765    0751  1077          STA I 17
```

```
0766    0752  1023          LDA I 3
0767    0753  1077          STA I 17
0770    0754  0235          XSK I 15
0771    0755  6722          JMP GETCHR+3     /MORE WORDS
0772    0756  0000  CHRRET,  0                /GO BACK
0773    0757  0011  SENSIT,  CLR
0774    0760  0016          NOP              /SXL I 12
0775    0761  0016          NOP              /JMP .-1
0776    0762  1060          STA I
0777    0763  0000  MATCH,   0
1000    0764  0070          SET I 10
1001    0765  0763          MATCH
1002    0766  1020          LDA I
1003    0767  0001          1
1004    0770  0405          SXL 5
1005    0771  1150          ADM 10
1006    0772  1020          LDA I
1007    0773  0002          2
1010    0774  0406          SXL 6
1011    0775  1150          ADM 10
1012    0776  1020          LDA I
1013    0777  0004          4
1014    1000  0407          SXL 7
1015    1001  1150          ADM 10
1016    1002  1020          LDA I
1017    1003  0010          10
1020    1004  0410          SXL 10
1021    1005  1150          ADM 10
1022    1006  1020          LDA I
1023    1007  0020          20
1024    1010  0411          SXL 11
1025    1011  1150          ADM 10
1026    1012  1020          LDA I
1027    1013  2122          SNSCOD!2000
1030    1014  2763          ADD MATCH
1031    1015  4003          STC 3
1032    1016  1003          LDA 3
1033    1017  6740          JMP STRIP
1034                  /
1035    1020  1000  DISIT,   LDA
1036    1021  0000          0
1037    1022  5054          STC DISRET
1040    1023  0643          LDF 3
1041    1024  0074          SET I 14
1042    1025  7776          DSCTBL-1!2000
1043    1026  0061          SET I 1
1044    1027  0377          377
1045    1030  0063          SET I 3
1046    1031  7776          -1
1047    1032  0011          CLR
1050    1033  1774          DSC I 14
1051    1034  1774          DSC I 14         /BOTH HALVES
1052    1035  0223          XSK I 3
1053    1036  7732          JMP .-4
1054    1037  0073          SET I 13
1055    1040  2307          HITTBL-1!2000
1056    1041  0061          SET I 1
1057    1042  0377          377
1060    1043  0063          SET I 3
1061    1044  7776          -1
1062    1045  1020          LDA I
1063    1046  7737          -40
1064    1047  1773          DSC I 13         /HIT
```

```
1065    1050  1773          DSC I 13
1066    1051  0223          XSK I 3
1067    1052  7045          JMP .-5
1070    1053  7023          JMP DISIT+3
1071    1054  0000  DISRET,  0
1072                /
1073    1055  4137  MOVED0,  STC BUFF1
1074    1056  0204          XSK 4
1075    1057  6000          JMP 0           /MOVED ALREADY
1076    1060  0044          SET 4
1077    1061  0011          11              /MOVE REACTION
1100    1062  6000          JMP 0
1101                /
1102    1063  7727  TIMER,   -50
1103    1064  4132  MOVED1,  STC BUFF2
1104    1065  0205          XSK 5
1105    1066  6000          JMP 0
1106    1067  0045          SET 5
1107    1070  0011          11
1110    1071  6000          JMP 0
1111                /
1112    1072  4133  MOVED2,  STC BUFF3
1113    1073  0206          XSK 6
1114    1074  6000          JMP 0
1115    1075  0046          SET 6
1116    1076  0011          11
1117    1077  6000          JMP 0
1120                /
1121    1100  4134  MOVED3,  STC BUFF4
1122    1101  0207          XSK 7
1123    1102  6000          JMP 0
1124    1103  0047          SET 7
1125    1104  0011          11
1126    1105  6000          JMP 0
1127                /
1130    1106  4135  MOVED4,  STC BUFF5
1131    1107  0210          XSK 10
1132    1110  6000          JMP 0
1133    1111  0050          SET 10
1134    1112  0011          11
1135    1113  6000          JMP 0
1136                /
1137                        SEGMNT 2
1140                        *20
1141    0020  0077          SET I 17
1142    0021  7677          -100
1143    0022  7000          JMP 0AINIT
1144    0023  0043          COMNT
1145    0024  0033          ANSWER
1146    0025  0237          XSK I 17
1147    0026  6002          JMP .-4
1150    0027  0067          SET I 7
1151    0030  3777          3777
1152    0031  0600          LIF 0
1153    0032  6557          JMP 0STRT
1154    0033  0000  ANSWER,  0
1155    0034  0000          0
1156    0035  0000          0
1157    0036  0000          0
1160    0037  0000          0
1161    0040  0000          0
1162    0041  0000          0
1163    0042  0000          0
```

```
1164        0043  0610
1164        0044  0522
1164        0045  0540
1164        0046  2705
1164        0047  4007
1164                    COMNT,  TEXT ZFHERE WE GO
1165        0050  1743
1165        0051  0640
1165        0052  4040
1165        0053  4040
1165        0054  0107
1165        0055  0111
1165        0056  1634
1165                    F     AGAIN\Z
1166        0057  7000  ITI,     JMP QAINIT
1167        0060  0064          ITIC
1170        0061  0033          ANSWER
1171        0062  7053          JMP QARFSH
1172        0063  7053          JMP QARFSH
1173                    ITIC,   TEXT Z
1174                    F
1175        0064  4306
1175                    F
1176        0065  4306
1176                    F
1177        0066  4306
1177                    F
1200        0067  4306
1200        0070  4306
1200        0071  4040
1200        0072  4040
1200        0073  4040
1200        0074  2411
1200        0075  1505
1200        0076  4017
1200        0077  2524
1200        0100  3400
1200                    F       TIME OUT\Z
1201                    /
1202        0101  0640  SAVRES, LDF 0
1203        0102  1000          LDA
1204        0103  2741          CHAR!2000
1205        0104  1060          STA I
1206        0105  0000  CSAV,    0
1207        0106  1000          LDA
1210        0107  2630          HIT!2000
1211        0110  1060          STA I
1212        0111  0000  HSAV,    0
1213        0112  1000          LDA
1214        0113  2004          2004
1215        0114  1060          STA I
1216        0115  0000  FIN1,    0
1217        0116  1000          LDA
1220        0117  2005          2005
1221        0120  1060          STA I
1222        0121  0000  FIN2,    0
1223        0122  1000          LDA
1224        0123  2006          2006
1225        0124  1060          STA I
1226        0125  0000  FIN3,    0
1227        0126  1000          LDA
1230        0127  2007          2007
1231        0130  1060          STA I
```

```
1232    0131  0000  FIN4,   0
1233    0132  0644          LDF 4
1234    0133  1000          LDA
1235    0134  0105          CSAV
1236    0135  1067          STA I 7
1237    0136  0207          XSK 7
1240    0137  0456          SKP
1241    0140  6224          JMP END
1242    0141  1000          LDA
1243    0142  0111          HSAV
1244    0143  1067          STA I 7
1245    0144  0207          XSK 7
1246    0145  0456          SKP
1247    0146  6224          JMP END
1250    0147  1000          LDA
1251    0150  0115          FIN1
1252    0151  1067          STA I 7
1253    0152  0207          XSK 7
1254    0153  0456          SKP
1255    0154  6224          JMP END
1256    0155  1000          LDA
1257    0156  0121          FIN2
1260    0157  1067          STA I 7
1261    0160  0207          XSK 7
1262    0161  0456          SKP
1263    0162  6224          JMP END
1264    0163  1000          LDA
1265    0164  0125          FIN3
1266    0165  1067          STA I 7
1267    0166  0207          XSK 7
1270    0167  0456          SKP
1271    0170  6224          JMP END
1272    0171  1000          LDA
1273    0172  0131          FIN4
1274    0173  1067          STA I 7
1275    0174  0207          XSK 7
1276    0175  0456          SKP
1277    0176  6224          JMP END
1300    0177  0461          SNS I 1
1301    0200  6224          JMP END
1302    0201  0600          LIF 0
1303    0202  6557          JMP QSTRT
1304                  /
1305    0203  0057  CRLF1,   SET 17
1306    0204  0000          0
1307    0205  1020          LDA I
1310    0206  0215          215
1311    0207  6214          JMP PUT1
1312    0210  1020          LDA I
1313    0211  0212          212
1314    0212  6214          JMP PUT1
1315    0213  6017          JMP 17
1316                  /
1317    0214  0056  PUT1,    SET 16
1320    0215  0000          0
1321    0216  0500          IOB
1322    0217  6041          TSF
1323    0220  6216          JMP .-2
1324    0221  0500          IOB
1325    0222  6046          TLS
1326    0223  6016          JMP 16
1327                  /
1330                  /
```

```
1331    0224  0644  END,    LDF 4
1332    0225  6203          JMP CRLF1
1333    0226  0061          SET I 1
1334    0227  3777          3777
1335    0230  0016  SETIT,   NOP
1336    0231  0063          SET I 3
1337    0232  7737          -40
1340    0233  6203          JMP CRLF1
1341    0234  6203  PUTIT,   JMP CRLF1
1342    0235  1021          LDA I 1
1343    0236  6214          JMP PUT1
1344    0237  1020          LDA I
1345    0240  0240          240
1346    0241  6214          JMP PUT1
1347    0242  1021          LDA I 1
1350    0243  6214          JMP PUT1
1351    0244  1020          LDA I
1352    0245  0240          240
1353    0246  6214          JMP PUT1
1354    0247  1020          LDA I
1355    0250  0240          240
1356    0251  6214          JMP PUT1
1357    0252  0062          SET I 2
1360    0253  7773          -4
1361    0254  1021          LDA I 1
1362    0255  0600          LIF 0
1363    0256  6256          JMP CONVRT
1364    0257  0222          XSK I 2
1365    0260  6254          JMP .-4
1366    0261  0462          SNS I 2
1367    0262  0000          HLT
1370    0263  0223          XSK I 3
1371    0264  6234          JMP PUTIT
1372    0265  0201          XSK 1
1373    0266  6230          JMP SETIT
1374    0267  0000          HLT
1375                        NOLIST
2354                        SEGMNT 3
2355                        *0
2356                  /
2357    0000  0000  DSCTBL,  0
2360    0001  0000           0
2361    0002  0000           0
2362    0003  0000           0
2363    0004  0000           0
2364    0005  0000           0
2365    0006  0000           0
2366    0007  0000           0
2367                  /
2370    0010  0000  HITTBL,  0
2371    0011  0000           0
2372    0012  0000           0
2373    0013  0000           0
2374    0014  0000           0
2375    0015  0000           0
2376    0016  0000           0
2377    0017  0000           0
2400    0020  4020  CHRDIS,  4020
2401    0021  2055           2055          /?
2402    0022  4477           4477
2403    0023  7744           7744          /A
2404    0024  5177           5177
2405    0025  2651           2651          /B
```

```
2406    0026  4136          4136
2407    0027  2241          2241          /C
2410    0030  4177          4177
2411    0031  3641          3641          /D
2412    0032  4577          4577
2413    0033  4145          4145          /E
2414    0034  4477          4477
2415    0035  4044          4044          /F
2416    0036  4136          4136
2417    0037  2645          2645          /G
2420    0040  1077          1077
2421    0041  7710          7710
2422                /H
2423    0042  7741          7741
2424    0043  0041          0041          /I
2425    0044  4142          4142
2426    0045  4072          4072          /J
2427    0046  1077          1077
2430    0047  4324          4324          /K
2431    0050  0177          0177
2432    0051  0301          0301          /L
2433    0052  3077          3077
2434    0053  7730          7730          /M
2435    0054  3077          3077
2436    0055  7706          7706          /N
2437    0056  4177          4177
2440    0057  7741          7741          /O
2441    0060  4477          4477
2442    0061  3044          3044          /P
2443    0062  4276          4276
2444    0063  0376          0376          /Q
2445    0064  4477          4477
2446    0065  3146          3146          /R
2447    0066  5121          5121
2450    0067  4651          4651          /S
2451    0070  4040          4040
2452    0071  4077          4077          /T
2453    0072  0177          0177
2454    0073  7701          7701          /U
2455    0074  0176          0176
2456    0075  7402          7402          /V
2457    0076  0677          0677
2460    0077  7701          7701          /W
2461    0100  1463          1463
2462    0101  6314          6314          /X
2463    0102  0770          0770
2464    0103  7007          7007          /Y
2465    0104  4543          4543
2466    0105  6151          6151          /Z
2467    0106  0000          0
2470    0107  0000          0
2471    0110  0000          0
2472    0111  0000          0
2473    0112  0000          0
2474    0113  0000          0
2475    0114  0000          0
2476    0115  0000          0
2477    0116  0000          0
2500    0117  0000          0
2501    0120  0000          0
2502    0121  0000          0
2503                /
2504                /
```

```
2505    0122  0240  SNSCOD, 240
2506    0123  0311          311
2507    0124  0305          305
2510    0125  0323          323
2511    0126  0301          301
2512    0127  0314          314
2513    0130  0317          317
2514    0131  0325          325
2515    0132  0316          316
2516    0133  0324          324
2517    0134  0303          303
2520    0135  0320          320
2521    0136  0322          322
2522    0137  0315          315
2523    0140  0310          310
2524    0141  0304          304
2525                  /
2526    0142  0000  TTYCOD, 0
2527    0143  0004          4                /A
2530    0144  0000          0                /B
2531    0145  0012          12               /C
2532    0146  0017          17               /D
2533    0147  0002          2                /E
2534    0150  0000          0                /F
2535    0151  0000          0                /G
2536    0152  0016          16               /H
2537    0153  0001          1                /I
2540    0154  0000          0                /J
2541    0155  0000          0                /K
2542    0156  0005          5                /L
2543    0157  0015          15               /M
2544    0160  0010          10               /N
2545    0161  0006          6                /O
2546    0162  0013          13               /P
2547    0163  0000          0                /Q
2550    0164  0014          14               /R
2551    0165  0003          3                /S
2552    0166  0011          11               /T
2553    0167  0007          7                /U
2554    0170  0000          0                /V
2555    0171  0000          0                /W
2556    0172  0000          0                /X
2557    0173  0000          0                /Y
2560    0174  0000          0                /Z
2561                  /
2562                  /
2563                  /
2564                  /PROGRAM ACCEPTS STIMULUS CODE FROM
2565                  /EITHER THE TTY (IF SENSE SWITCH 5 IS UP) OR VIA A
                       OCTAL CODE
2566                  /VIA SENSE LINES 5,6,7,10, AND 11
2567                  /(IF SNS 5 IS DOWN). A GROUND TO SXL 12
2570                  /INDICATES THAT SENSE LINE  (SCODE) CODIFICATION S
                       COMPLETE
2571                  /
2572                  /DISPLAY IS MAINTAINED AS LONG AS SENSE LINE
2573                  /12 IS GROUNDED
2574                  /PROGRAM THEN MONITORS THE RESPONSE CODE
2575                  /VIA SXL 0-4 FOR CORRESPONDANCE TO THE S-CODE
2576                  /THE ALPHA EQUIVALENT OF THE S-CODE IS DISPLAYED
2577                  /ON TOP, THE R-CODE IS DISPLAYED ON THE BOTTOM.
2600                  /1-DISIT
2601                  /2- UNUSED
```

```
2602                    /3-SCRATCH
2603                    /4-UNUSED
2604                    /5-UNUSED
2605                    /6-UNUSED
2606                    /7-UNUSED
2607                    /10 SUM AND MATCH POINTER
2610                    /11-MSEC TIMER
2611                    /12- NUMBER OF CHARACTERS
2612                    /13-DISIT R-CODE
2613                    /14-DISIT S-CODE
2614                    /15 NUMBER OF CHARACTERS
2615                    /16-R-CODE
2616                    /17-S-CODE
2617                    /TESTS FOR ANY R CODE, SETS TIMER
2620                    /SETS RELAYS
2621                    /SHOWS REINFORCEMENT
2622                    /
2623                    /
2624                    /WIRING CONFIGURATION
2625                    /
2626                    /
2627                    /         IN CPU ROOM
2630                    /
2631                    /RESPONSES COME TO CPU ROOM VIA COAX A-F
2632                    /THESE ARE CONNECTED VIA PATCH CORD TO
2633                    /COMPARATORS 5-10
2634                    /
2635                    /REFERENCE IS ADJUSTED TO GIVE PULSE OUT
2636                    /OF COMPARATORS WHEN THE SELECTED LEVEL IS
2637                    /EXCEEDED.
2640                    /
2641                    /COMPARATOR 5 POS OUT IS CONNECTED TO DIODE GATE A
2642                    /            6 POS OUT IS CONNECTED TO DIODE GATE B
2643                    /            7 POS OUT IS CONNECTED TO DIODE GATE C
2644                    /           10 POS OUT IS CONNECTED TO DIODE GATE D
2645                    /OUTPUT OF THESE GATES IS PATCHED TO INPUT 3
2646                    /SET SOURCE TO - AND THRESHOLD TO JUST +
2647                    /
2650                    /SENSE LINE 5 TO HUMAN 7
2651                    /           6          8
2652                    /           7          9
2653                    /          10         10
2654                    /
2655                    /HUMAN 5 TO COMPARATOR 2-    POS OUT OF 2 TO INPUT
                        1
2656                    /+ SOURCE, +THRESHOLD
2657                    /VERIFY
2660                    /
2661                    /K0 IS CONNECTED TO PATCH 1 AT BOTTOM OF CPU
2662                    /K1 IS CONNECTED TO PATCH 2 AT BOTTOM OF CPU
2663                    /K2 IS CONNECTED TO PATCH 5
2664                    /K3 IS CONNECTED TO PATCH 6
2665                    /K4 IS CONNECTED TO PATCH 7
2666                    /K5 IS CONNECTED TO PATCH 8
2667                    /
2670                    //
2671                    /         IN HUMAN ROOM
2672                    /
2673                    /VERIFY CONNECTIONS TO CPU INTERFACE
2674                    /GREEN TO 1 HI
2675                    /BROWN TO 5 HI
2676                    /RED TO 6 HI
2677                    /ORANGE TO 7 HI
```

```
2700                    /YELLOW TO 8 HI
2701                    /
2702                    /WHITE TO 8 LOW
2703                    /THE LOWS OF 1, 2, 5, 6, 7, AND 8 ARE
2704                    /TIED TOGETHER
2705                    /
2706                    /SOUNDPROOF ROOM CONNECTIONS
2707                    /OSCILLATOR PATCH CORD TO HEAD SET IN ROOM
2710                    /
2711                    /OPERATING INSTRUCTIONS
2712                    /
2713                    /TURN POWER STRIP TO ON
2714                    /     THIS APPLIES POWER TO ALL POWER SUPPLIES
2715                    /                        THE POLYGRAPH
2716                    /                        THE TAPE TIMER
2717                    /                        THE TAPE MARKER
2720                    /
2721                    /YOU MUST TURN ON THE TAPE MARKER WHEN READY TO RU
2722                    /
2723                    /S CODE, R CODE, AND AUDITORY R CODE PRESENTATIONS
                        ARE CONTROLLED
2724                    /AS FOLLOWS
2725                    /
2726                    /  TO DISABLE AUDITORY FEEDBACK, UNPLUG OSC CONT U
                         PLUG
2727                    /  TO DISABLE S CODE PRESENTATION, PLACE S CODE SW
                        TCHES UP
2730                    /  TO DISABLE R CODE PRESENTATION, PLACE R CODE SW
                        TCHES UP
2731                    /
2732                    /SNS 1 DOWN FORCES PRINTOUT OF ALL PREVIOUS TRIALS
2733                    /THIS SPACE IS RESERVED FOR DANISH COMMENTS

NO ERRORS

AASTRT 0615
ANSWER 4033
BLANK  0223
BNKRET 0236
BUFF1  0137
BUFF2  0132
BUFF3  0133
BUFF4  0134
BUFF5  0135
CHAR   0741
CHRDIS 6020
CHRRET 0756
CLAB   6133
CLEN   6134
CLKSET 0576
CLLR   6132
CLSA   6135
CLSK   6131
CNVCMP 0422
COMNT  4043
CONV   3400
CONVRT 0256
CRLF   0247
CRLF1  4203
CSAV   4105
DISIT  1020
DISRET 1054
DSCTBL 6000
```

```
END     4224
ERRORS  0544
FIN1    4115
FIN2    4121
FIN3    4125
FIN4    4131
FOUR    0022
GETCHR  0717
GETKBD  5521
HIT     0630
HITTBL  6010
HSAV    4111
INT     0041
IOF     6002
ION     6001
IT1     4057
ITIC    4064
KRB     6036
KSF     6031
K1024   0352
K243    0574
K244    0623
K3072   0331
MATCH   0763
MINUS1  0425
MOVED   0457
MOVED0  1055
MOVED1  1064
MOVED2  1072
MOVED3  1100
MOVED4  1106
NEG     0655
NXT     0163
ONE     0020
PUT     0237
PUTIT   4234
PUT1    4214
QAB     5004
QACA    5015
QACHAR  5655
QACKLF  5621
QACNTR  5604
QAD     5026
QAE     5050
QAEXIT  5635
QAF     5516
QAG     5062
QAH     5114
QAI     5131
QAINIT  5000
QAJ     5136
QAK     5305
QAKRB   6036
QAL     5175
QALEGL  5575
QAM     5101
QAN     5223
QAO     5231
QAP     5242
QAQ     5263
QARFSH  5053
QAT     5270
QATLS   6046
```

```
QATPE   5644
QATSF   6041
QATY    5536
QAU     5506
QAV     5316
QAW     5512
QAX     5424
QAY     5412
QAZ     5301
QSTRT   0557
RCLSA   0074
RETBIN  0456
RMF     6244
RRTEMP  0475
SAMTIM  0676
SAVRES  4101
SENSIT  0757
SETIT   4230
SNSCOD  6122
SPACE   0167
STRIP   0740
TDONE   0221
TEN     0023
THREE   0704
TIME    0577
TIMER   1063
TLS     6046
TRLSRT  0543
TRY10   0125
TRY5    0106
TRY6    0113
TRY7    0120
TSF     6041
TTYCOD  6142
TWENTY  0024
TWO     0021
TYPIT   0147
VAR     0301
```

APPENDIX D

DATA ANALYSIS SOFTWARE

The programs described in this appendix deal with the analysis of data acquired by program ARPA6 (Appendix C). These programs operate sequentially in a chained manner. The sequence is initiated by starting ARPAXFR, the other programs are then automatically called in sequence.

PROGRAM NAME: ARPAXFR

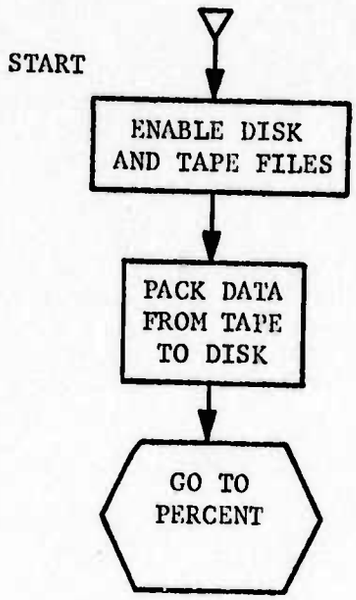
FUNCTION: Transfer S code, R code, and latency data from tape and store on disk in a packed format.

LANGUAGE: FOCAL-12

DESCRIPTION: Data acquired by ARPA6 are saved on sequential LINC tape blocks. This program retrieves data from LINC tape and stores them in consecutive locations on the disc facility.

PROGRAM CALLED: PERCENT

FLOWCHART FOR ARPAXFR



```
W
C FOCAL-12

01.05 T %4.0
01.06 L O,F2,I,#001,14
01.10 L O,F1,I,#001,1
01.20 F I=0,256;D 2
01.30 O S
01.90 L G,$PERCENT,13

02.10 F J=0,5;S A(J)=F1(I*256+J)
02.11 I (A(1)-163)2.12,2.12,2.2
02.12 S A(1)=160
02.20 F J=0,5;S F2(I*6+J)=A(J)
*
```

PROGRAM NAME: PERCENT

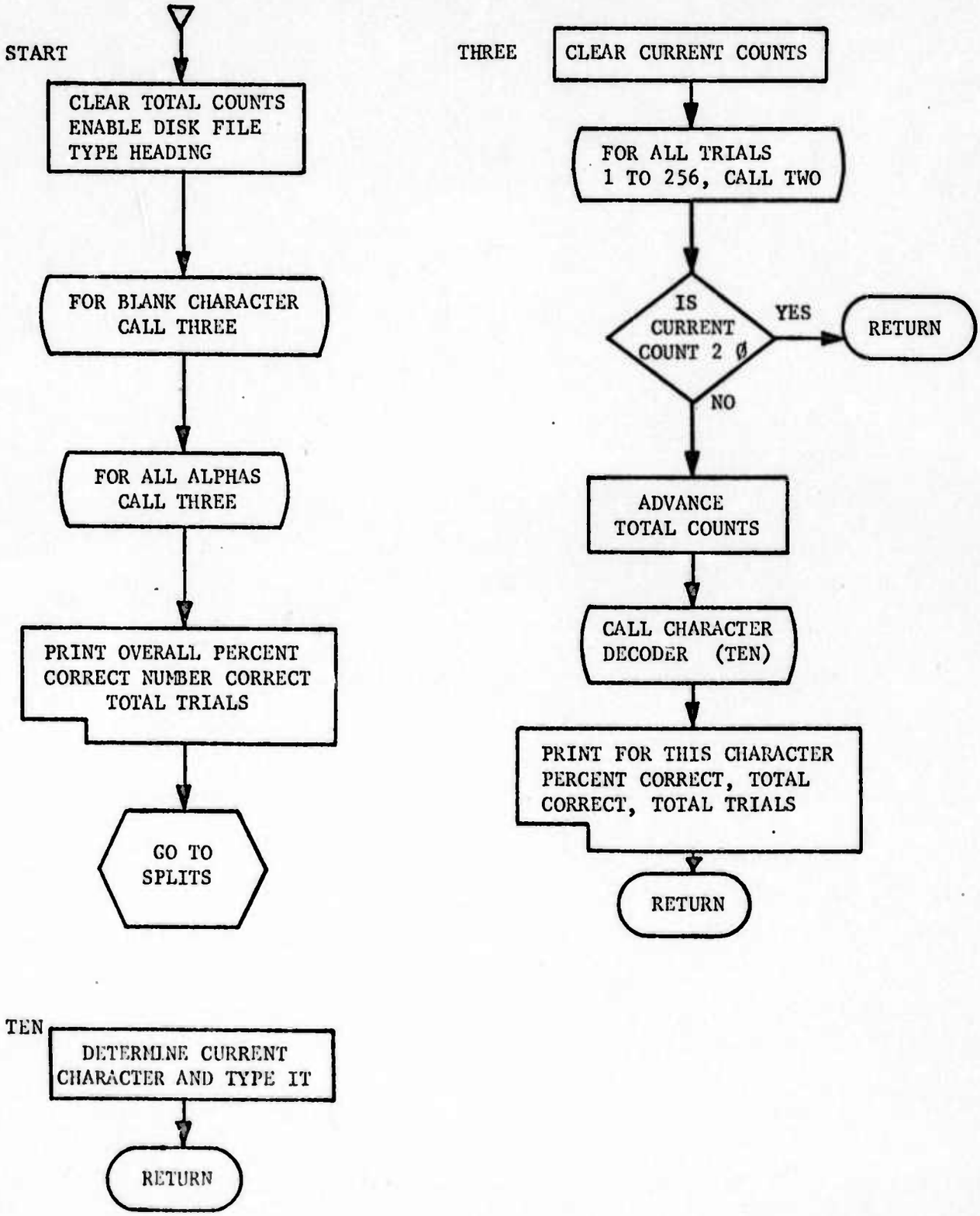
FUNCTION: Determine the percent of responses which were correct for each of 16 characters.

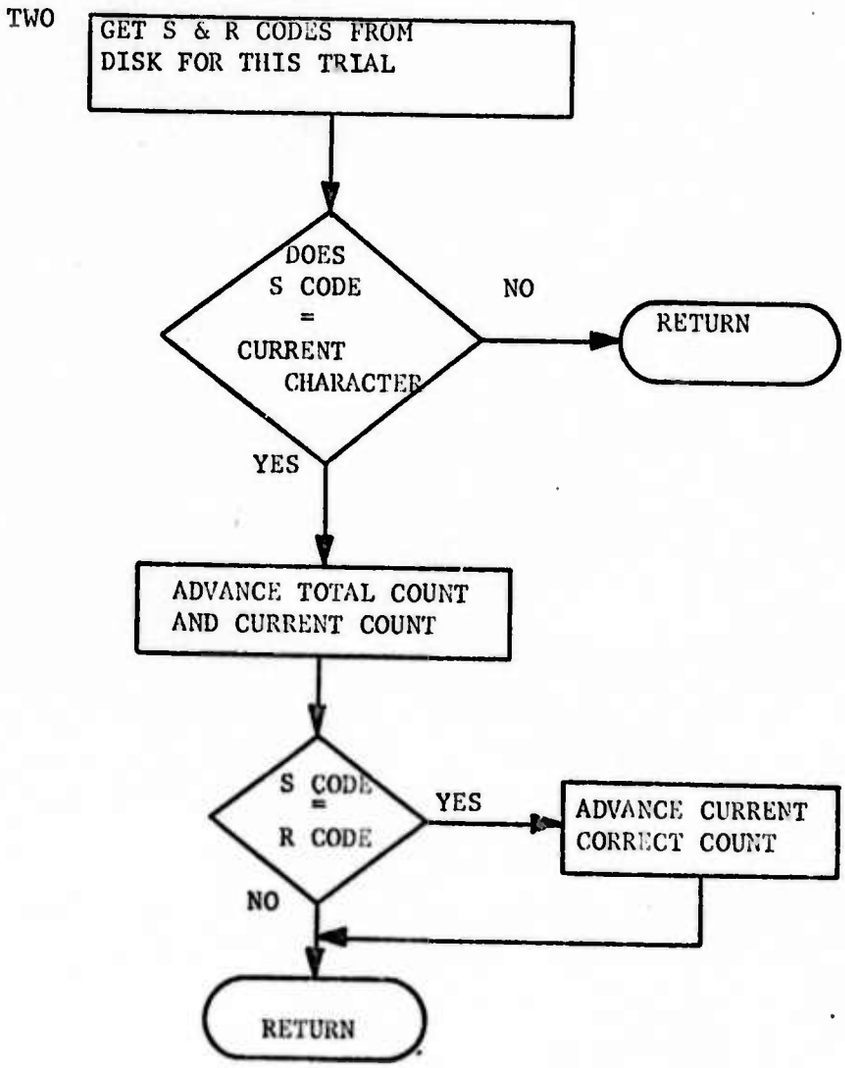
LANGUAGE: FOCAL-12

DESCRIPTION: S code data records packed on the disc are examined for correspondance to each of 16 characters sequentially. If the S code matches the current character, the current counter is incremented, and the R code is then tested for correspondence. If the R code matches the S code then the current correct counter is incremented. At the conclusion of testing all trials for S code correspondence the percent of correct responses are printed out.

PROGRAM CALLED: SPLIT

FLOWCHART FOR PERCENT




TWO
GET S & R CODES FROM DISK FOR THIS TRIAL
DOES S CODE = CURRENT CHARACTER
NO
RETURN
YES
ADVANCE TOTAL COUNT AND CURRENT COUNT
S CODE = R CODE
YES
ADVANCE CURRENT CORRECT COUNT
NO
RETURN

```
C FOCAL-12

01.05 T %4.0
01.06 O T;S N3=0;S N4=0
01.10 L O,F1,1,#001,14
01.15 T "OVERALL",!
01.20 S C=160;D 3
01.21 F C=193,215;D 3
01.85 T !,(N3*100)/N4,N3,N4,!;O S
01.90 L G,$SPLITS,13

02.10 S D=I*6
02.11 S A2=F1(D);S A3=F1(D+1)
02.20 I (A2-C)2.21,2.22;
02.21 R
02.22 S N2=N2+1;S N4=N4+1
02.23 I (A2-A3)2.21,2.3,2.21
02.30 S N=N+1

03.20 S N2=0;S N=0
03.25 F I=0,255;D 2
03.30 I (N)3.31,3.31,3.32
03.31 R
03.32 S N3=N3+N;S A1=C;D 10;T " "
03.40 T %4.1,N*100/N2,N,N2,!
```

```
10.10 I (A1-190)10.6;
10.11 I (A1-194)10.66;
10.12 I (A1-196)10.67;
10.13 I (A1-197)10.68;
10.14 I (A1-198)10.69;
10.15 I (A1-201)10.7;
10.16 I (A1-202)10.71;
10.17 I (A1-205)10.72;
10.18 I (A1-206)10.73;
10.19 I (A1-207)10.74;
10.20 I (A1-208)10.75;
10.21 I (A1-209)10.76;
10.22 I (A1-211)10.77;
10.23 I (A1-212)10.78;
10.24 I (A1-213)10.79;
10.25 I (A1-214)10.8;
10.60 I (A1-160)10.61,10.81,10.61
10.61 I (A1-163)10.62,10.82,10.62
10.62 T "?";R
10.66 T "A";R
10.67 T "C";R
10.68 T "D";R
10.69 T "E";R
10.70 T "H";R
10.71 T "I";R
10.72 T "L";R
10.73 T "M";R
10.74 T "N";R
10.75 T "O";R
10.76 T "P";R
10.77 T "R";R
10.78 T "S";R
10.79 T "T";R
10.80 T "U";R
10.81 T " ";R
10.82 T "#";R
*
```

PROGRAM NAME: SPLIT

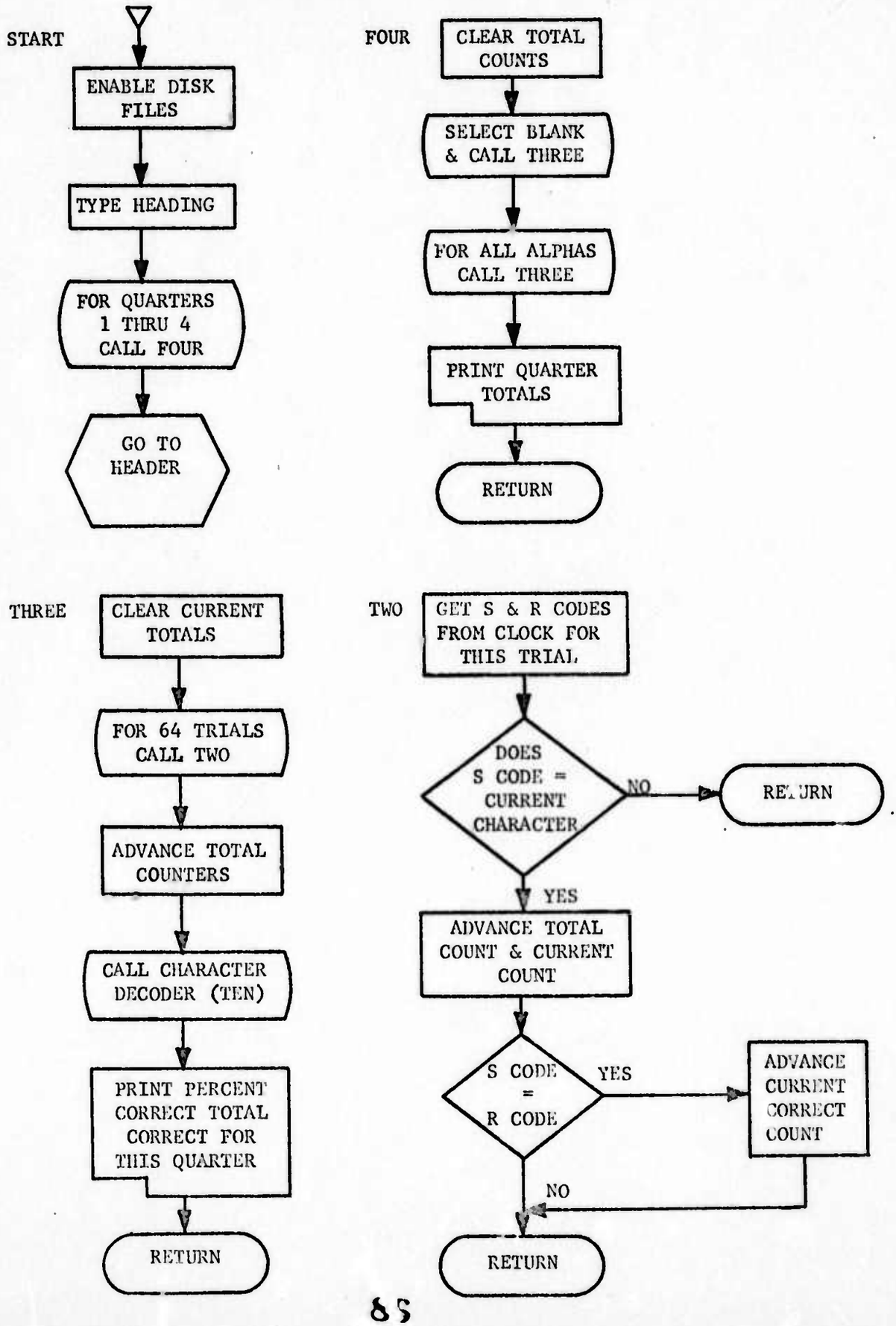
FUNCTION: Determine the percent of responses which were correct for each of 16 characters in quarters (64) of the total session.

LANGUAGE: FOCAL-12

DESCRIPTION: For each successive 64 trials, the S code data records packed on the disc are examined for correspondence to each of 16 characters sequentially. If the S code matches the current character, the current counter is incremented, and the R code is then tested for correspondence. If the R code matches the S code then the current correct counter is incremented. At the conclusion of testing all trials for S code correspondence the percent of correct responses are printed out.

PROGRAM CALLED: HEADER

FLOWCHART FOR SPLITS



```
C FOCAL-12

01.05 T %4.0
01.06 O T
01.10 L O,F1,I,#001,14
01.15 T !,"QUARTER ANALYSIS",!
01.20 F J=0,3;T "QUARTER",J+1,!;D 4
01.85 O S
01.90 L G,$HEADER,13

02.10 S D=((J*64)+J1)*6
02.11 S A2=F1(D);S A3=F1(D+1)
02.20 I (A2-C)2.21,2.22;
02.21 R
02.22 S N2=N2+1;S N4=N4+1
02.23 I (A2-A3)2.21,2.3,2.21
02.30 S N=N+1

03.20 S N2=0;S N=0
03.25 F J1=0,63;D 2
03.30 I (N)3.31,3.31,3.32
03.31 R
03.32 S N3=N3+N;S A1=C;D 10;T " "
03.40 T %4.1,N*100/N2,N,N2,!

04.05 S N3=0;S N4=0
04.10 S C=160;D 3
04.20 F C=193,215;D 3
04.30 T !,(N3*100)/N4,N3,N4,!,!
```

```
10.10 I (A1-190)10.6;
10.11 I (A1-194)10.66;
10.12 I (A1-196)10.67;
10.13 I (A1-197)10.68;
10.14 I (A1-198)10.69;
10.15 I (A1-201)10.7;
10.16 I (A1-202)10.71;
10.17 I (A1-205)10.72;
10.18 I (A1-206)10.73;
10.19 I (A1-207)10.74;
10.20 I (A1-208)10.75;
10.21 I (A1-209)10.76;
10.22 I (A1-211)10.77;
10.23 I (A1-212)10.78;
10.24 I (A1-213)10.79;
10.25 I (A1-214)10.8;
10.60 I (A1-160)10.61,10.81,10.61
10.61 I (A1-163)10.62,10.82,10.62
10.62 T "?";R
10.66 T "A";R
10.67 T "C";R
10.68 T "D";R
10.69 T "E";R
10.70 T "H";R
10.71 T "I";R
10.72 T "L";R
10.73 T "M";R
10.74 T "N";R
10.75 T "O";R
10.76 T "P";R
10.77 T "R";R
10.78 T "S";R
10.79 T "T";R
10.80 T "U";R
10.81 T " ";R
10.82 T "#";R
*
```

PROGRAM NAME: HEADER

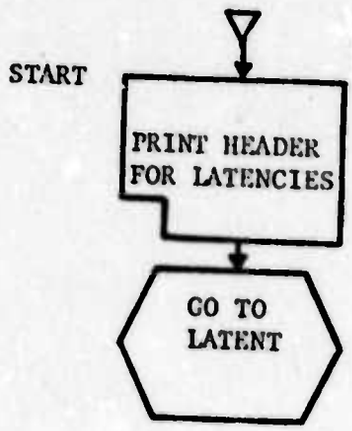
FUNCTION: Print heading for latency analysis.

LANGUAGE: FOCAL-12

DESCRIPTION: Same as function.

PROGRAM CALLED: LATENT

FLOWCHART FOR HEADER



```
C FOCAL-12

01.10 O T
01.15 T " PERCENTS                          MUSCLES",!
01.20 T "                                RL      RT"
01.21 T "    LT      LL",!
01.90 O S
01.99 L G,$LATENT,13
*
```

PROGRAM NAME: LATENT

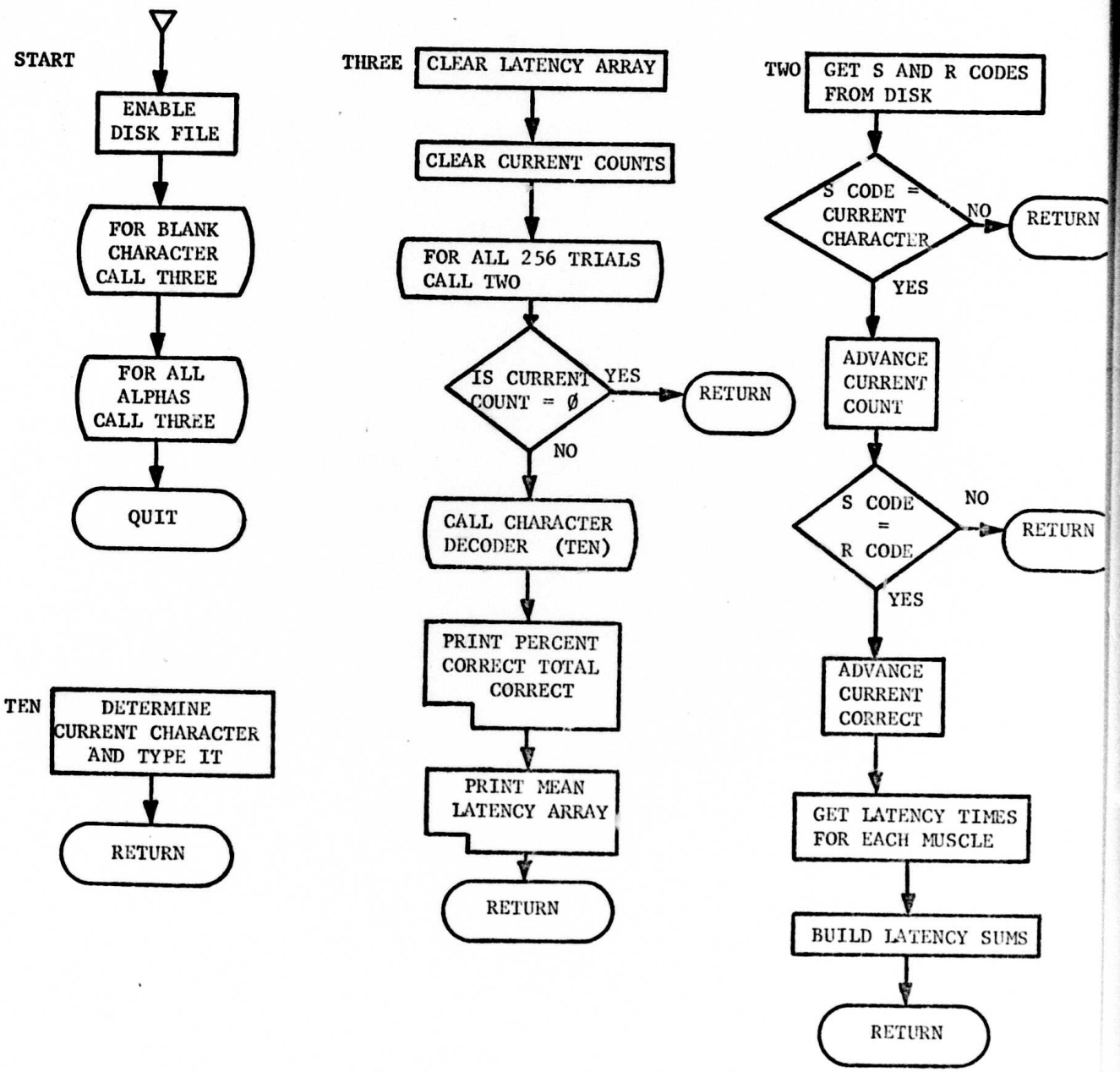
FUNCTION: Determine average latency to responsd for each muscle associated with a character.

LANGUAGE: FOCAL-12

DESCRIPTION: S code data packed on the disc are examined for correspondence to, sequentially, each of 16 characters. If the S code matches the current character and the R code, then the latency data for each of four muscle responses are retrieved and used to update running averages.

PROGRAM CALLED: none

FLOWCHART FOR LATENT



```
C FOCAL-12

01.06 O T
01.10 L O,F1,1,#801,14
01.20 S C=160;D 3
01.21 F C=193,215;D 3
01.85 Q

02.10 S D=1+6
02.11 S A2=F1(D);S A3=F1(D+1)
02.20 I (A2-C)2.21,2.22;
02.21 R
02.22 S N2=N2+1
02.23 I (A2-A3)2.21,2.3,2.21
02.30 S N=N+1
02.40 F K=1,4;S S(K)=S(K)+F1(D+K+1)
02.50 F K=5,8;S S(K)=S(K)+F1(D+K-3)*F1(D+K-3)

03.10 F K=1,8;S S(K)=0
03.20 S N2=0;S N=0
03.25 F I=0,255;D 2
03.30 I (N)3.31,3.31,3.32
03.31 R
03.32 S A1=C;D 10;T " "
03.40 T %4.1,N*100/N2,N,N2
03.50 F K=1,4;D 5
03.60 T !,!

05.10 I (S(K))5.11,5.2,5.2
05.11 T "       ";R
05.20 T S(K)/N
```

```
10.10 I (A1-190)10.6;
10.11 I (A1-194)10.66;
10.12 I (A1-196)10.67;
10.13 I (A1-197)10.68;
10.14 I (A1-198)10.69;
10.15 I (A1-201)10.7;
10.16 I (A1-202)10.71;
10.17 I (A1-205)10.72;
10.18 I (A1-206)10.73;
10.19 I (A1-207)10.74;
10.20 I (A1-208)10.75;
10.21 I (A1-209)10.76;
10.22 I (A1-211)10.77;
10.23 I (A1-212)10.78;
10.24 I (A1-213)10.79;
10.25 I (A1-214)10.8;
10.60 I (A1-160)10.61,10.81,10.61
10.61 I (A1-163)10.62,10.82,10.62
10.62 T "?";R
10.66 T "A";R
10.67 T "C";R
10.68 T "D";R
10.69 T "E";R
10.70 T "H";R
10.71 T "I";R
10.72 T "L";R
10.73 T "M";R
10.74 T "N";R
10.75 T "O";R
10.76 T "P";R
10.77 T "R";R
10.78 T "S";R
10.79 T "T";R
10.80 T "U";R
10.81 T " ";R
10.82 T "/";R
*
```

APPENDIX E

ARPA INSTRUCTIONS TO SUBJECT

ARPA Instructions to Subjects

This is a study of human performance. We are interested in ways to improve human performance. You will be given various signals, each of which calls for a specific response from you. You will make many wrong responses at first, but your performance will improve with the number of trials. Don't worry about making a wrong response--they are useful to us too, but try your best to make the right one.

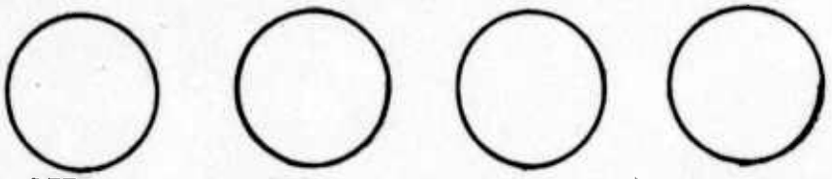
The signal will consist of a pattern of lights which are arranged in a horizontal row. There is a total of four lights, and the pattern may consist of any combination of lights from "all off" to "all on".

Your response will consist of a movement of your thumbs and 4th fingers on both hands either one at a time or in various combinations. This movement causes a change in the electrical potential of the activated muscle. We can monitor and record this change of potential as an electromyogram (EMG). This is done by placing a surface electrode on the skin immediately overlying the activated muscle. (This involves no pins or clamps--the electrode merely lies flat on the skin). There is no shock involved. With this electrode system we can only record--not stimulate. When you make a response, we will monitor the EMG only--we are not interested in the actual, overt movement. If you can generate a potential of adequate magnitude without a large amount of movement--by all means, do so.

Assignment of Fingers and Lights

Basically, the experiment works like this: When one or more of the four top, yellow, lights is lit, it is a signal for you to move the muscle which has been assigned to that light.

The assignments are as follows:



LEFT LITTLE FINGER | LEFT THUMB | RIGHT THUMB | RIGHT LITTLE FINGER

Place your open hands palms down on the armrests of the chair. The lights and muscles are in the same sequence horizontally.

As different combinations of lights flash on, try to match them with the appropriate combination of movements. Your response should come as soon as possible after the lights appear. A new trial will be given every 6-10 seconds, and there will be a total of 256 trials per day. A run will last about one hour.

(Errors):

You can make two types of errors in your response: 1) you can fail to match with an EMG a light which is lit; 2) you can make a muscle-response which is not called for--that is, the corresponding light is not lit.

In both cases, you will fail to see the square red light on the right side of the panel light up. This light is only turned on by a correct response. When you see it lit up after a trial, you know that you have made the desired response. Please try to get accuracy first, and speed second.

The following information is only given to the biofeedback subjects.

Obviously, this is a learning task, and you are learning to give the correct response to the "stimulus" lights. To aid you in learning, you receive several kinds of feedback.

First, feedback is represented by the green "response" lights directly under the "stimulus" lights. You turn on these lights yourself, with the EMGs generated by your muscles. Again, each light corresponds to a muscle--the same muscle as the light directly above it. These lower lights light up individually as soon as you make the response. If the pattern of the "response"-lights matches that of the lit "stimulus"-lights exactly, you have made the correct response and the red light on the right will light up.

In addition to the lights, there are four speakers arranged around you in the booth. These correspond to the various muscles we are recording from and each will emit a beep-tone when the appropriate muscle is activated. The speaker on your immediate right will be activated by your right little finger, the speaker in front of you on the right corresponds to your right thumb, and the correspondence is the same on the left: rear speaker--little finger, front speaker--thumb. These speakers, like the lights, will tell you when you are activating the muscles they are linked to.

We have designed these visual and auditory signals to let you know what sort of response you are making. They are meant to help you in your task--learning to match the "stimulus"-light pattern presented to you with the greatest possible accuracy and speed. Use them to your advantage.